CHAPTER 4.5 RESULTS OF ESTUARINE PROBABILISTIC MONITORING 2007-2012

General Introduction

Program Origins and Evolution: The Virginia Department of Environmental Quality (DEQ) initiated its two ambient probabilistic monitoring (ProbMon) programs in 2000, with the advent of its Millennium 2000 Water Quality Monitoring Strategy. The Free-running Freshwater ProbMon Program was modeled after EPA's earlier National Environmental Monitoring and Assessment Program (EMAP) and is coordinated from the headquarters of DEQ's Blue Ridge Regional Office (BRRO, Roanoke). Freshwater ProbMon involves all six (formerly seven) of DEQ's current regional offices. The Estuarine Probabilistic Monitoring Program, as summarized in this Chapter, is coordinated from DEQ's Central Office (CO) in Richmond, and involves only those regional offices which have tidal estuarine waters within their jurisdictions: Tidewater Regional Office (TRO, Virginia Beach), Piedmont Regional Office (PRO, Glen Allen), and Northern Regional Office (NRO, Woodbridge). It began by affiliation with the Coastal 2000 Initiative, which was fostered and supported by grants from EPA's Office of Research and Development (ORD) from 2000 through 2004. By the end of that period, the Coastal 2000 Initiative Program had become well established and evolved into the National Coastal Assessment (NCA) Program. As a result of its transition from an experimental to a permanent status, the NCA Program was transferred from EPA's ORD to the Office of Water (OW), with continued (although somewhat reduced) federal funding during the 2005-2006 transition period. Direct federal funding of Estuarine ProbMon during the first seven years provided for the purchase of tow-vehicles and boats, other equipment such as multiprobe sondes and sediment grabs, expendable supplies, and the training of DEQ's central and regional office field teams. During the same period, DEQ integrated additional resources from EPA's Interstate Chesapeake Bay Program and from state general funds to develop and support its own state-designed program, as described below. A special targeted supplement to annual federal §106 Water Quality Monitoring grants has continued to partially fund DEQ's ProbMon Programs. NCA has now become the National Coastal Condition Assessment (NCCA, including the freshwaters of the Great Lakes), and is one component of the National Aquatic Resources Survey (NARS). Resources provided by NARS cycle on a five-year schedule through five aquatic resource classes: (1) streams, (2) large rivers, (3) lakes & reservoirs, (4) wetlands, and (5) coastal waters. NARS resources helped fund the 2010 Near-shore Oceanic Survey summarized in DEQ's 2012 Integrated 305(b)/303(d) Water Quality Report, and NARS resources are scheduled to return to the NCCA Program in 2015 and 2020.

Design and Geographic Distribution: In most years, DEQ's state design Estuarine ProbMon Program collects samples at 50 probabilistic estuarine sites, selected by computer in a completely random manner from designated estuarine (non-oceanic) tidal waters. Designated waters in this design exclude the Chesapeake Bay mainstem and the broad tidal tributary mainstems of the lower James, York and Rappahannock Rivers. Included are their narrower upper tidal reaches (transitional and tidal freshwaters) and all tidal tributaries and embayments along their lengths, as well as Virginia's tidal tributaries and embayments of the Potomac River[1] and of the Bay itself[2]. Tidal tributaries and embayments of Coastal Delmarva and the Back Bay – North Landing River region are also included. The Chesapeake Bay mainstem and the lower, broader regions of its three major Virginia tributaries are excluded because they are sufficiently characterized by the Chesapeake Bay Tidal Water Quality Monitoring and Assessment Program and are included as four sampling strata within the Chesapeake Bay Probabilistic Benthic Monitoring Survey. In the state design, the only preference applied in the process of selection is the requirement that 70% (N = 35) of the annual sites be from inland tidal waters of the Chesapeake Bay and North Landing River watersheds, and 30% (N = 15) of the sites be from the coastal Delmarva peninsula and Back Bay. At five-year intervals (2010, 2015, 2020, etc.) DEQ's Estuarine ProbMon Program is integrated with the National Aquatic Resources Survey (NARS) / National Coastal Condition Assessment (NCCA) Program, the design of which may include a varying number of sites within the Chesapeake, James, York and Rappahannock mainstems. The number of Virginia estuarine sites selected for NARS surveys varies from cycle to cycle, but is usually between 20 and 25. When resources permit, DEQ has complemented the national design with enough stations from the state design to complete a total of 50 sites, although the exact 70% / 30% division between inland and coastal tidal waters may not be maintained. In 2010, DEQ collected samples from only 23 estuarine sites, plus two Quality Assurance (QA) revisits. Complementary DEQ resources that year were added to regional and national EPA resources in order to perform the 50-site Near-Shore Oceanic Survey that was reported on in Chapter 4.8 of the 2012 305(b)/303(d) Integrated Water Quality Report (2012 IR; DEQ-WQA, 2012). The six-year assessment window (2007 – 2012) encompassed by the current Integrated Report (2014 IR) includes 275 sets of estuarine samples collected from 273 sites; both sets of samples from the two 2010 revisit sites have been included, since they were collected several weeks apart.

[1] The vast majority of the Potomac River mainstem is within Maryland's jurisdiction.

[2] The Chesapeake mainstem is excluded from the DEQ state design, and is only sampled within the Estuarine ProbMon Program at five-year intervals, when participating in the NARS/NCCA national survey design.

The geographic distribution and salinity zones of the 273 probabilistic estuarine sites visited (275 sampling events) during the six-year period are illustrated in the map of Figure 4.5-1. The salinities classified here represent the bottom salinities at the time of sampling, associated with the benthic community samples collected at the sites. The color-coded symbols on the map indicate the salinity zone of each site, as summarized in Table 4.5-1 below. The bottom salinities between visits to two 2010 NARS sites varied slightly, but gave identical salinity class results (N = 275 site visits). The percentages and confidence intervals listed in the table represent the percentages among the 275 site visits with measured salinity values, and are not representative of Virginia's estuarine waters as a whole. If the area of the entire Chesapeake Bay mainstem and the lower tidal portions of the James, York, and Rappahannock Rivers were to be included in the Commonwealth's sampling design, the tidal freshwater and oligohaline percentages would be much reduced, and the saltwater percentage would be much greater! All 50 euhaline sites (salinity > 30.0‰) were located adjacent to oceanic waters along the Delmarva coast.

Table 4.5-1 Numbers and Proportions of the Estuarine ProbMon Sites Occurring in Various Salinity Zones. The tabled percentages are representative primarily of the more restricted DEQ state sampling design that does not include Virginia's portion of the Chesapeake Bay mainstem (see text for details).

Estuarine Salinity Zones	Observed Sites	Percentage of Estuarine ProbMon sites and 95% Confidence Interval	
Tidal Freshwater (< 0.5‰)	22	8.00 ± 3.22%	
Oligohaline - Transitional (0.5 - 5.0‰)	38	13.82 ± 4.10%	
Mesohaline (> 5.0 - 18.0‰)	81	29.45 ± 5.41%	Saltwater 215 (78.18 ± 4.90%)
Polyhaline (> 18.0 - 30.0‰)	84	30.55 ± 5.47‰	
Euhaline (> 30.0 - 40.0‰)	50	18.18 ± 4.58‰	
Total	275	100.00 ± 0.00%	

The vast majority of the sites fell within the minor tidal tributaries and embayments of the Chesapeake Bay watershed or in the estuarine waters of coastal Delmarva and the Back Bay / North Landing River region of southeastern Virginia. Eleven sites within the Chesapeake Bay mainstem and its embayments are a result of the 2010 NARS/NCCA sampling design.

Parameters Measured and Field Methods: DEQ's Estuarine ProbMon Program adheres closely to the same selection of water quality and sediment quality parameters as does the NCCA Program. Complete hydrologic profiles of temperature, pH, specific conductance/salinity and dissolved oxygen are collected at each site with a multiprobe sonde. In addition to Secchi depth, a profile of available photosynthetically active radiation (PAR) is measured from the surface down to near bottom, or to a depth where underwater readings approach zero. Additional chemical and biological parameters measured in near-surface (0.5 m) waters are listed in Table 4.5-2. With the exception of bacterial samples, which are collected by hand from just below the surface, and the clean metals samples described below, samples for all parameters listed in the table are collected by pump and hose from a near-surface depth of 0.5 meters. Bacterial samples were analyzed for (1) fecal coliform bacteria, (2) *Escherichia coli* bacteria, and (3) bacteria of the genus *Enterococcus*. From 2008 through 2011 additional samples were collected for the analysis of clean dissolved and total trace metals in the water column. Clean metals samples were siphoned from just below the surface directly into submerged, pre-cleaned Nalgene bottles. In saltwater, Aluminum (Al), Antimony (Sb), Arsenic (As), Cadmium (Cd), Calcium (Ca), Copper (Cu), Iron (Fe), Lead (Pb), Magnesium (Mg), Manganese (Mn), Mercury (Hg), Nickel (Ni), Potassium (K), Selenium (Se), Sodium (Na), and Zinc (Zn) are normally analyzed, along with Hardness in mg $CaCO_3$/L. In tidal freshwater, Barium (Ba), Beryllium (Be), Chromium (Cr), Silver (Ag), and Thallium (Tl) are added and Potassium (K) and Sodium (Na) are dropped. Vanadium (V) was added to both freshwater and saltwater analyses beginning in the summer of 2010[3].

Composite sediment samples for chemical, toxicological, and particle size / Total Organic Carbon (TOC) analyses were collected with six-inch petite Ponar dredges (grabs). The top 2.0 to 3.0 cm were collected from each grab, transferred to a stainless steel vessel, and homogenized until a total of approximately four liters was accumulated.

[3] Vanadium, commonly associated with raw petroleum, was added to clean metals analyses in the summer of 2010, in response to the Deepwater Horizon petroleum spill in the Gulf of Mexico. There was some concern that the Gulf Stream might transport petroleum contamination into Mid-Atlantic coastal waters. Baseline Vanadium measurements will also be useful for comparisons once petroleum prospecting begins along the Mid-Atlantic Continental Shelf.

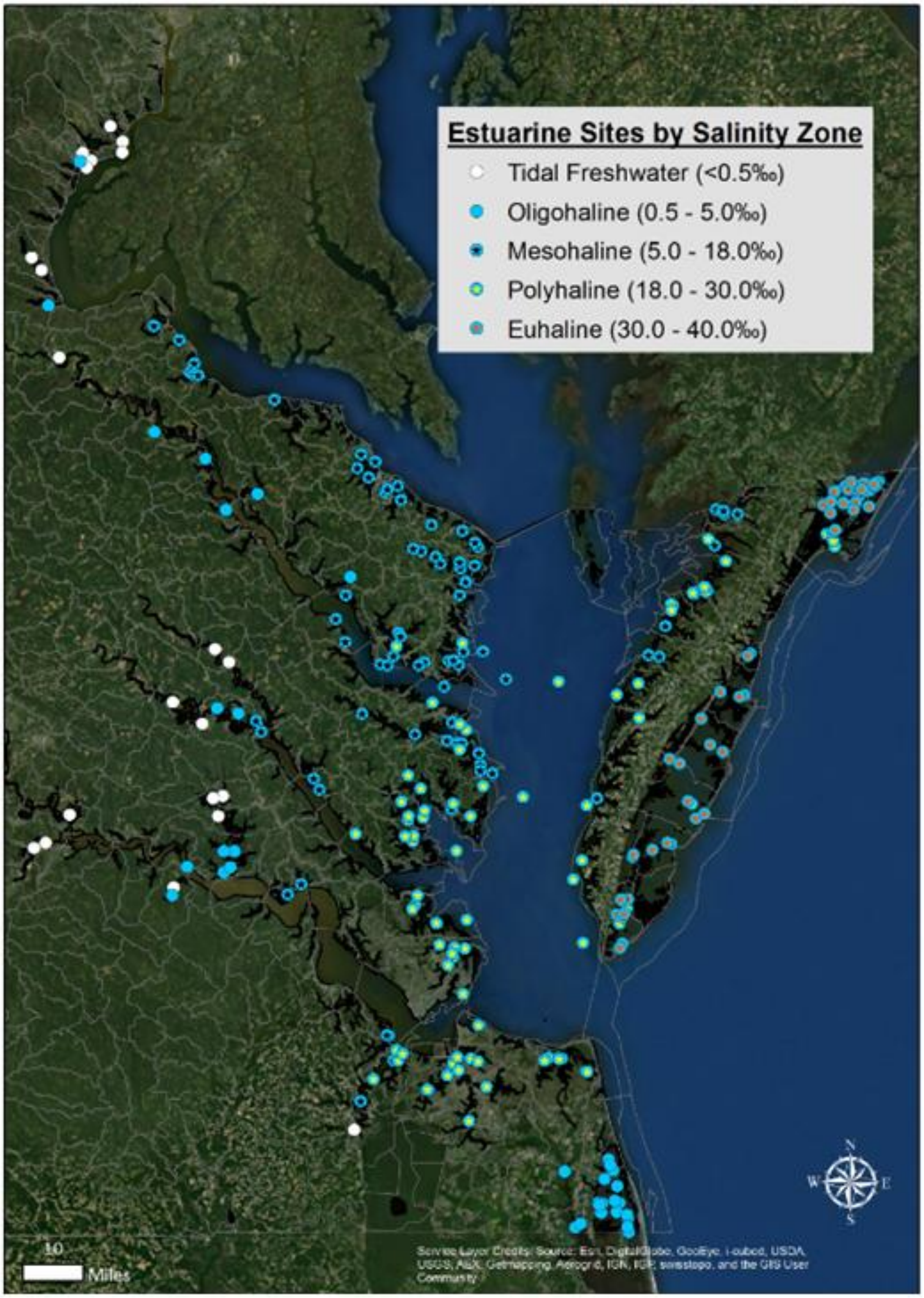


Figure 4.5-1 Geographic distribution of the 273 Estuarine ProbMon Sites Sampled in Virginia Waters between 2007 and 2012, with their Respective Salinity Zones. The salinities coded here indicate the bottom salinity at the time of sampling, and do not necessarily agree with the nominal salinities of the corresponding, predefined CBP segments. Twenty-three of the sites, including eleven within the Chesapeake Bay mainstem, were selected within the 2010 NARS/NCCA national design. Two 2010 NARS sites were revisited after a two week to one month interval, providing a total of 275 site visits within the six-year 2007 - 2012 assessment window. In some cases, individual sites from different years are so close together that their symbols overlap and an accurate count is difficult in this and in subsequent figures.

Table 4.6-2 – Parameters Analyzed in the Water Column – Estuarine ProbMon Program
(Units are mg/L unless otherwise specified.)

Chlorophyll a (µg/L)	Orthophosphate-P dissolved	Total suspended solids
	Phosphorus Total dissolved*	Fixed suspended solids*
Nitrate-N dissolved	Silica dissolved (as SiO_2)*	Volatile suspended solids*
Nitrite-N dissolved	Nitrogen particulate*	
Nitrate + Nitrite-N dissolved*	Phosphorus particulate*	*Escherichia coli* (cfu/dL)*
Ammonia-N dissolved	Carbon particulate*	*Enterococcus* (cfu/dL)*
Nitrogen-Total dissolved*		Fecal coliforms (cfu/dL)*

* These parameters are Virginia DEQ add-ons or modifications of the original NCCA parameter suite. Dissolved and total trace metals were also sampled as add-on parameters from 2008 – 2011 (see text for a complete description). (cfu/dL – colony forming units per deciliter = per 0.1 liter)

Table 4.6-3 - Chemical Parameters Analyzed in the Sediment – Estuarine ProbMon Program

Polynuclear Aromatic Hydrocarbons
(N = 23 PAHs) (µg/Kg)

Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(e)pyrene
Benzo(k)fluoranthene
Benzo(g,h,i)perylene
Benzo(a)pyrene
Chrysene
Dibenz(a,h)anthracene
2,6-dimethylnaphthalene
Fluoranthene
Fluorene
Ideno(1,2,3-c,d)pyrene
1-methylnaphthalene
2-methylnaphthalene
1-methylphenanthrene
Naphthalene
Perylene
Phenanthrene
Pyrene
2,3,5-trimethylnaphthalene

Other Semi-volatile Organics (N = 2) (µg/Kg)

Biphenyl
Dibenzothiophene (synfuel)

Organochlorine Pesticides Other than DDT
(N = 14) (µg/Kg)

Aldrin
Alpha-Chlordane
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Lindane (gamma-BHC)
Mirex
Toxaphene
Trans-Nonachlor

DDT and its metabolites
(N = 6) (µg/Kg)

2,4'-DDD	4,4'-DDE
4,4'-DDD	2,4'-DDT
2,4'-DDE	4,4'-DDT

Polychlorinated Biphenyls
(N = 21 PCBs) (µg/Kg)

Congeners: 8, 18, 28, 44, 52, 66, 101, 105, 110/77, 118, 126, 128, 138, 153, 170, 180, 187, 195, 206, 209

Metals
(N = 15) (mg/Kg)

Aluminum
Antimony
Arsenic
Cadmium
Chromium
Copper
Iron
Lead
Manganese
Mercury
Nickel
Selenium
Silver
Tin
Zinc

Other Measurements
(N = 4)

Total organic carbon
(g/Kg as Carbon, converted to % as C)
Percent sand
Percent silt
Percent clay

Three sediment subsamples were subsequently separated for chemical analyses of metals (~125 cm^3), organics (~500 cm^3), and particle size/TOC (~500 cm^3). Approximately three liters of the homogenate were also separated for toxicity testing. The chemical parameters analyzed in surficial sediment samples are summarized in Table 4.5-3, above. The vast majority of the listed sediment parameters are also included in the recently published USGS priority list (Olsen, et al., 2013). Sediment toxicity tests consisted of ten-day static, acute tests with burrowing marine amphipod test organisms - with *Ampelisca abdita* prior to 2010 and with *Leptocheirus plumulosus* in 2010 and thereafter.

Two additional petite Ponar grabs were collected for benthic analyses. The contents of each grab were separately sieved gently through a 0.5 mm screen, and the contents of the sieve were subsequently transferred into a fabric sample bag. A single complete composite benthic sample consisted of the accumulated contents sieved from both grabs and represented a total substrate area of approximately 0.04 m^2. Bagged and labeled samples were immediately fixed by submersion in 10% phosphate-buffered formalin containing Rose Bengal stain.

All water column samples (chlorophyll, nutrients, suspended solids, bacteria, and trace metals) and sediment particle size / TOC samples were analyzed by the Division of Consolidated Laboratory Services (DCLS) of the Virginia Department of General Services (DGS) in Richmond. Sediment chemistry samples and sediment toxicity samples were analyzed by contracted commercial laboratories.

With the exception of the formalin-fixed benthic samples, all samples were maintained on wet ice until reaching the local DEQ regional office or laboratory. Samples destined for analysis at the state laboratories (DCLS) were shipped to Richmond on wet ice via contracted overnight courier service. Sediment samples destined for analysis by contracted commercial labs were kept refrigerated at the regional office and were shipped to Central Office (CO) on wet ice weekly. Sediment toxicity samples on blue ice were shipped from CO weekly via overnight air prior to 2011, and were hand delivered to Coastal Bioanalysts Inc. (Gloucester, VA) on wet ice every week or two beginning in 2011. Sediment chemistry samples were generally frozen and shipped or delivered to the appropriate laboratory at the halfway point and at the end of the field season, except for 2010. During participation in the national survey in 2010, sediment chemistry samples and sediment toxicity samples on wet ice were shipped weekly to Tetra Tech Inc. (Owings Mills, MD). Tetra Tech subsequently transshipped the chemistry samples to an EPA nationally-contracted chemistry lab.

Beginning in 2007, all of the probabilistic estuarine benthic samples collected within this program were processed by the Benthic Ecology Laboratory (BEL) at Old Dominion University (ODU), under the auspices of Dr. Daniel M. Dauer. Dr. Dauer participated in the development of the Chesapeake Bay Program's Benthic Index of Biotic Integrity (CBP B-IBI – Weisberg et al., 1997) and has been Virginia's lead estuarine benthic investigator since the beginning of the Chesapeake Bay Program in the mid-1980s. In addition to separating, identifying, and enumerating the benthic taxa in each sample, BEL calculates multiple metrics for each sample and provides site scores for the Chesapeake Bay Program Index of Biotic Integrity (CBP B-IBI – Weisberg et al., 1997), the Mid-Atlantic Regional B-IBI (MAIA B-IBI – Llansó et al., 2002a,b), and the EMAP benthic Index of Estuarine Condition for the Virginian Biogeographic Province (IEC-VP – Paul et al., 2001). Formalin-fixed benthic samples were accumulated at regional offices until the end of each field season, after which they were united and hand delivered to BEL/ODU.

Water Quality

General Considerations: The NCCA Program has traditionally (NCC Reports I-IV; U.S. EPA, 2001, 2004, 2008, 2012) used five parameters to characterize estuarine water quality; near-surface (1) dissolved inorganic Nitrogen (mg/L DIN), (2) dissolved inorganic Phosphorus (mg/L DIP), and (3) chlorophyll-a (µg/L Chl-a), (4) near-bottom dissolved Oxygen (mg/L DO), and (5) water clarity, expressed as the percent of available PAR reaching a specified 1.0 meter depth. A classification ("Good", "Fair", or "Poor") based on each of these parameters was subsequently integrated into an overall Water Quality Index (WQI) classification for the site. The concentrations of these same parameters are also included for consideration in site-specific weight-of-evidence assessments for the aquatic life designated use to be discussed later in the chapter.

On a national scale, the threshold concentrations of these parameters, differentiating among "Good", "Fair", and "Poor" water quality classes, vary regionally. For national coastal assessments, Virginia is included in the northeast region. For NCCA Report V, analyzing results from the 2010 survey and due for release late in 2014, modifications were suggested for some of the regional thresholds, and it was suggested that water clarity be eliminated as a parameter for inclusion in the WQI. Summaries of previous and proposed thresholds for the remaining four water quality parameters are presented in Table 4.5-4, below. Although Water Clarity may be excluded from the WQI for the 2014 NCCA Report, it has been included here for a tentative characterization of individual sites, with various caveats discussed below. Most of the modifications of classification thresholds proposed for the NCCA Report V were rejected during review by EPA's Scientific Advisory Committee (SAC), but the final thresholds to be applied for the 2014 NCCA Report V have not yet been announced. The following discussion of water quality in Virginia's estuaries is based primarily on the thresholds from earlier NCCA Reports I - IV, except where specifically indicated otherwise.

Table 4.5-4 National Coastal Condition Report Water Quality Indicators and Thresholds for the Northeast Coastal Region: A. Traditional - NCCR I through NCCR IV (U.S. EPA 2001, 2004a, 2008, 2012) **and B. Proposed Modifications for NCCR V** (in prep. 2014)**.** Blue values - relaxed threshold proposed, Red values - more stringent threshold proposed. Adapted from "Progress Update – National Webinar – National Coastal Condition Assessment." U.S. Environmental Protection Agency (14 January 2013).

A. National Coastal Condition Reports I – IV (U.S. EPA, 2001, 2004a, 2008, 2012)

	Chlorophyll-a (µg/L)		DIN (mg/L)		DIP (mg/L)		DO (mg/L)	
Region	Good to Fair	Fair to Poor	Good to Fair	Fair to Poor	Good to Fair	Fair to Poor	Good to Fair	Fair to Poor
NE	5	20	0.1	0.5	0.01	0.05	5	2

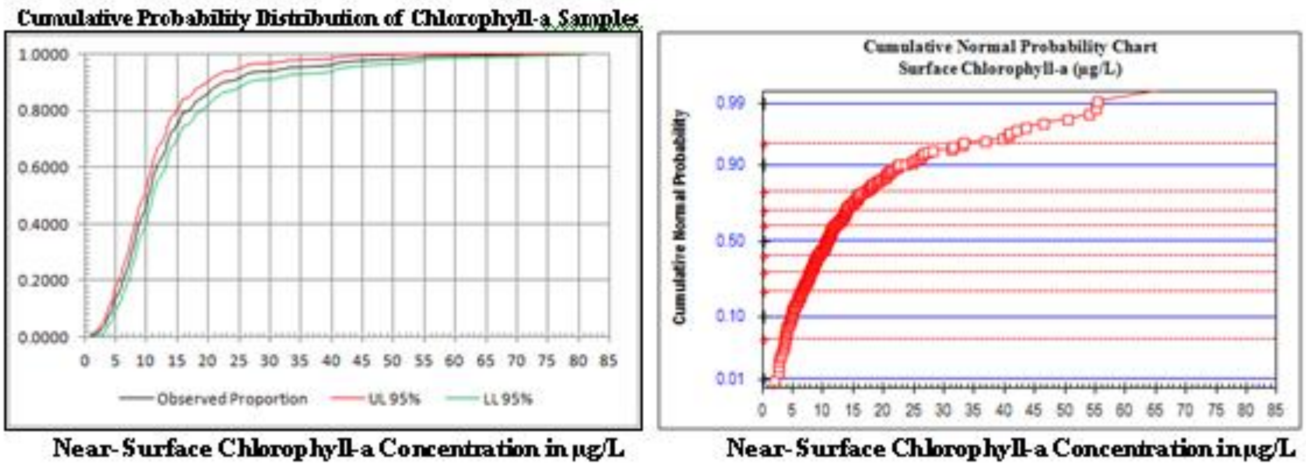
B. National Coastal Condition Report V – proposed threshold modifications

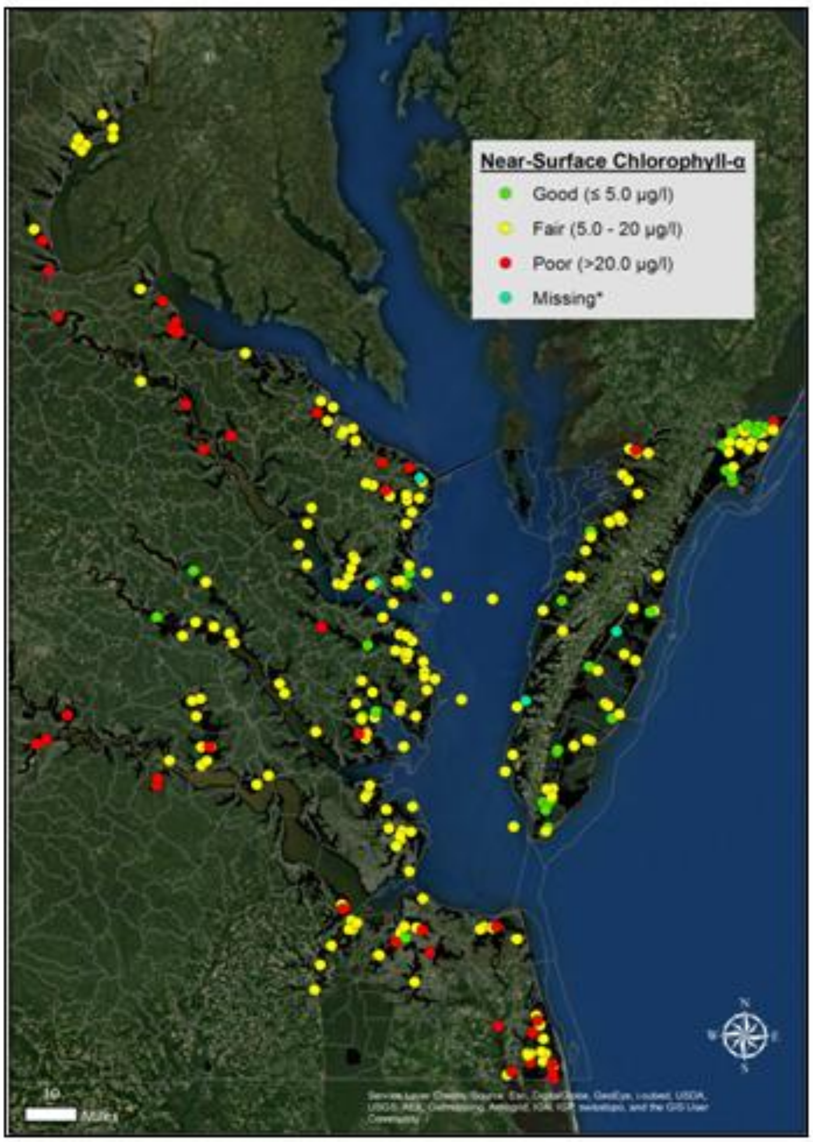
	Chlorophyll-a (µg/L)		DIN (mg/L)		DIP (mg/L)		DO (mg/L)	
Region	Good to Fair	Fair to Poor	Good to Fair	Fair to Poor	Good to Fair	Fair to Poor	Good to Fair	Fair to Poor
NE	10	20	0.2	0.5	0.05	0.1	5	3

Near-surface Chlorophyll-a: Chlorophyll-a (Chl-a) is used as an indirect measure of the quantity of phytoplankton in the water column. High values of chlorophyll-a, characteristic of excessive numbers of phytoplankton, are generally interpreted to result from nutrient enrichment or eutrophication of the associated water body.

Near-surface chlorophyll-a concentrations were analyzed in 271 of 275 samples from probabilistic estuarine sites (completeness = 98.55%); the missing four samples (1.45%) were all lost in the laboratory at the same time, when their glass extraction tubes broke during centrifugation. Of the 271 samples analyzed, 35 (12.92 ± 4.01%) were characterized as "Good" (< 5.0 µg/L Chl-a) using the older chlorophyll-a thresholds in Table 4.5-5-A, 197 sites (72.69 ± 5.33%) were classified as "Fair" and 39 (14.39 ± 4.52%) were classified as "Poor" (>20.0 µg/L Chl-a). The geographic, numerical, and statistical distributions of sites by chlorophyll-a class and the corresponding class thresholds are summarized in the maps and tables of Figure 4.5-2. The interpretation of cumulative probability distributions and normal probability charts is explained in Appendix 11 of this Report. The map in the Figure illustrates the geographic distribution of the 271 samples evaluated, classified, and color coded by their near-surface chlorophyll-a concentrations. In this figure, and in subsequent maps illustrating the classification of sites, the "Poor" sites are given priority in the overlay of symbols: order of precedence = "Poor" > "Fair" > "Missing" > "Good".

It is evident in Figure 4.5-2 that, for the most part, the sites in the "Poor" class fall within oligohaline and fresh waters in the upper tidal reaches of tributary streams and embayments. Virginia's portion of Back Bay and the North Landing River in the southeastern corner of the state are both oligohaline. Based on the NCCA chlorophyll thresholds for regional characterizations, Virginia's estuarine waters would receive an overall score of "Fair" for chlorophyll-a (10 - 20% of sites score "Poor," < 50% "Good"), especially for the tidal fresh and oligohaline waters of minor tributaries. The Chesapeake Bay mainstem and coastal Delmarva waters would also receive localized ratings of "Fair". The smooth curve of the cumulative normal probability chart for chlorophyll, beginning at low and continuing smoothly through higher concentrations, indicates that some degree of nutrient enrichment and eutrophication are probably prevalent throughout Virginia's estuarine waters.





Surface Chlorophyll-a (µg/L)	
N	271
Max	81.10
99th %tile	54.98
95th %tile	32.82
90th %tile	22.41
85.84th %tile	20.00
75th %tile	14.99
UL 95% Median	11.15
Median	10.41
LL 95% Median	9.67
25th %tile	7.18
12.91th %tile	5.00
10th %tile	4.59
5th %tile	3.55
1st %tile	2.23
Min	1.21
Average	13.05
Std. Dev.	10.55
Std. Err.	0.64

Figure 4.5-2 Geographic & Statistical Distributions and Characterizations of 271 Probabilistic Estuarine Sites Based upon Near-Surface Chlorophyll-a Values – µg/L (2007 – 2012). Cutpoint criteria of 5.0 and 20.0 µg/L are from NCCA Reports I – IV (U.S. EPA 2001, 2004a, 2008, 2012).

* Four missing chlorophyll-a values, identified by blue symbols in the figure, were the result of glass extraction tubes breaking during laboratory centrifugation.

Near-Surface Dissolved Inorganic Nitrogen: Concentrations of near-surface dissolved inorganic Nitrogen (DIN) were measured in 275 samples from 273 sites. DIN was calculated as the sum of the concentrations of dissolved nitrate (NO_3^-), dissolved nitrite (NO_2^-) and dissolved ammonium (NH_4^+) ions. Among the 275 samples, 251 (91.27 ± 3.35%) were classified as "Good" for DIN, 21 (7.64 ± 3.15%) were classified as "Fair", and three (1.09 ± 1.23%) were classified as "Poor".

The map presented in Figure 4.5-3 illustrates the geographic distribution of the 273 sites evaluated, classified, and color coded by their near-surface dissolved inorganic nitrogen concentrations. The only three sites that fell within the "Poor" class were all within the same 6th order sub-watershed (PL50 – 020700100805 - Potomac River-Occoquan Bay) and occurred during the summers of 2007 and 2008; two were in the lower reaches of Pohick Creek and the other was at the mouth of the Occoquan River, two neighboring tidal tributaries to the Potomac River. Locally, the watershed PL50 would receive a characterization of "Poor" (> 25% of sites score "Poor"), but an overall characterization of "Good" (< 10% of sites "Poor", > 50% of sites "Good") would apply to Virginia's estuaries as a whole. Based on more extensive bimonthly ambient watershed monitoring from 2001 - 2006, Occoquan Bay and Belmont Bay (watershed PL50), a complex Potomac River embayment, had already been listed as impaired by eutrophication in DEQ's 2008 Integrated Report (IR), based on elevated pH values.

The sharply curved form of the cumulative normal probability distribution at higher DIN concentrations (Figure 4.5-3) suggests the presence of Nitrogen enrichment wherever concentrations exceed 0.05 mg/L. This excess Nitrogen is probably of anthropomorphic origin – from wastewater treatment facilities and/or agriculture.

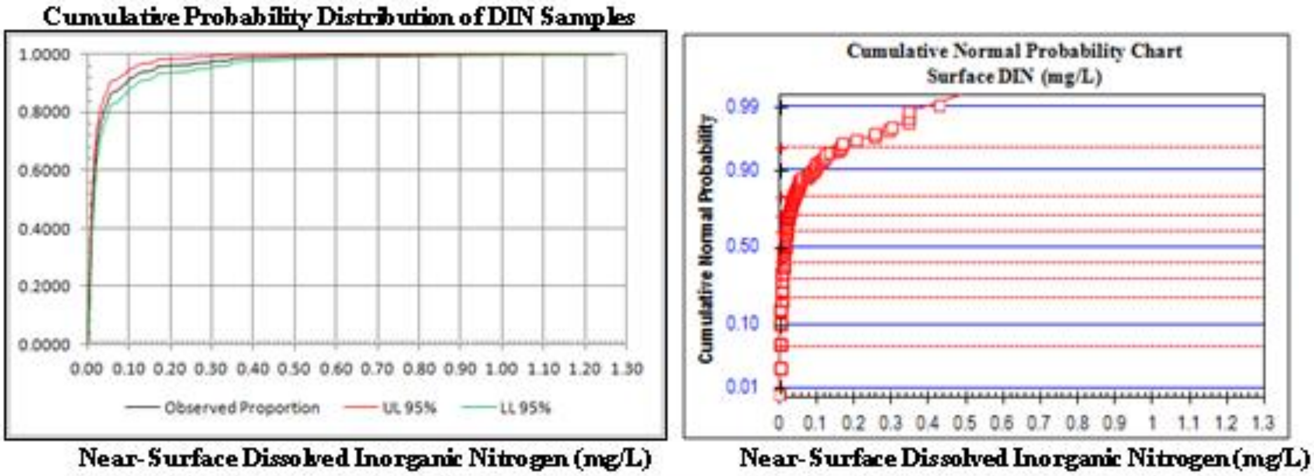
Recent discussions (EPA NARS conference call - 25 March 2014) about nutrient parameters for the 2015 NCCA survey questioned the appropriateness of DIN as a water quality indicator. DIN concentrations are often low when algal populations (and chlorophyll-a concentrations) are high, an indication that most of the dissolved nitrogen has been taken up by phytoplankton. The use of total Nitrogen (to include the cells of phytoplankton), as opposed to dissolved inorganic nitrogen, was suggested and this question will be discussed in future conference calls in preparation for the 2015 national survey.

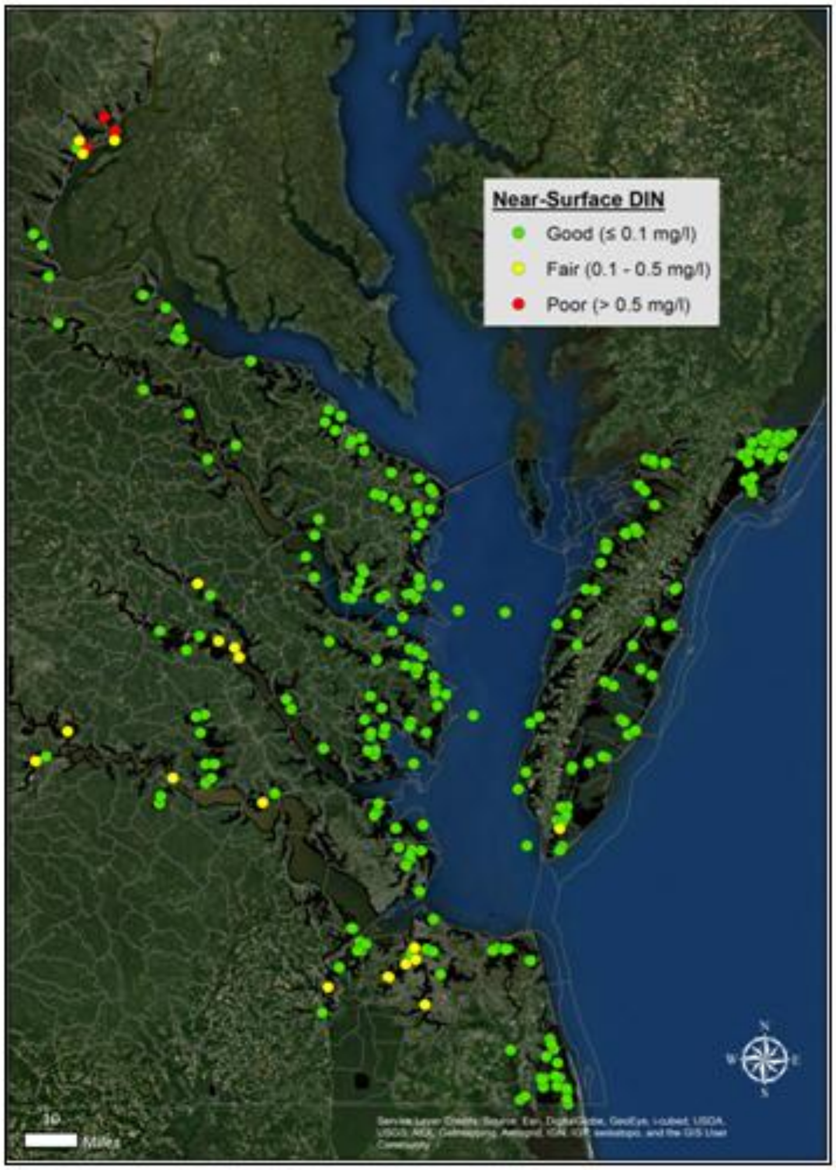
Near-Surface Dissolved Inorganic Phosphorus: Near-surface dissolved inorganic Phosphorus (DIP - also known as phosphate [PO_4^{-3}] or orthophosphate) concentrations were also measured in 275 samples from 273 sites. The geographic and statistical distributions of DIP classifications are illustrated in the map and graphs of Figure 4.5-4. One hundred thirty-eight (50.18 ± 5.92%) of the 275 samples were classified as "Good," 118 (42.91 ± 5.88%) were classified as "Fair", and 19 (6.91 ± 3.01%) were classified as "Poor."

In Figure 4.5-4 it is apparent that many of the sites with high ("Poor") DIP concentrations are associated with urban development in the Norfolk/Portsmouth region (Elizabeth River system). Oceanic phosphorus concentrations are generally higher than in estuarine regions, and the predominance of "Fair" and "Poor" sites at estuarine sites along coastal Delmarva may partially reflect that tendency. Phosphorus in stormwater runoff from poultry farms (manure) on the peninsula may also contribute to this geographic distribution, but don't appear to affect the Chesapeake side of the peninsula.

Virginia's estuaries earn an overall "Good" classification for DIP in regional waters, since less than 10% of sites score "Poor" and more than 50% of the sites score "Good". The Elizabeth River system would be scored as "Poor" on a more limited regional basis.

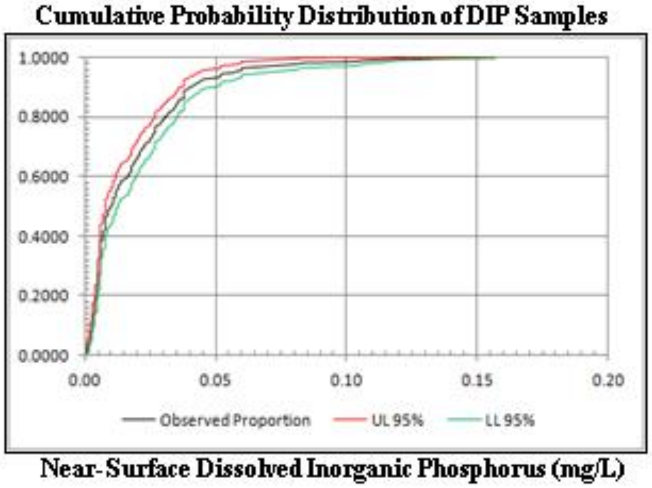
The use of dissolved inorganic Phosphorus as an indicator of water quality has been criticized on the same basis as DIN, and the potential use of total Phosphorus in the water column as an indicator of water quality will also be discussed in preparation for the 2015 NCCA survey.

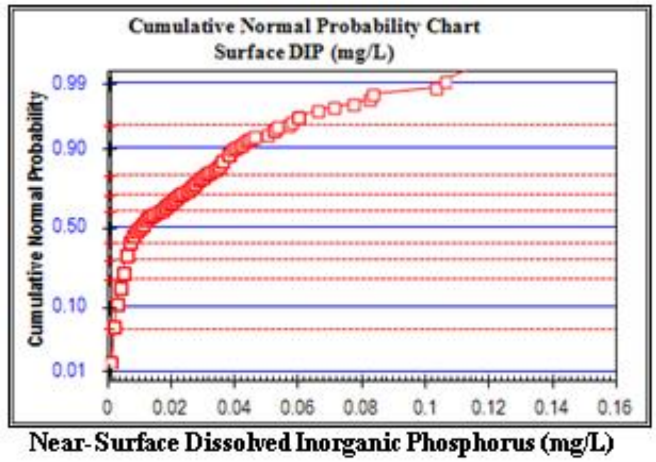


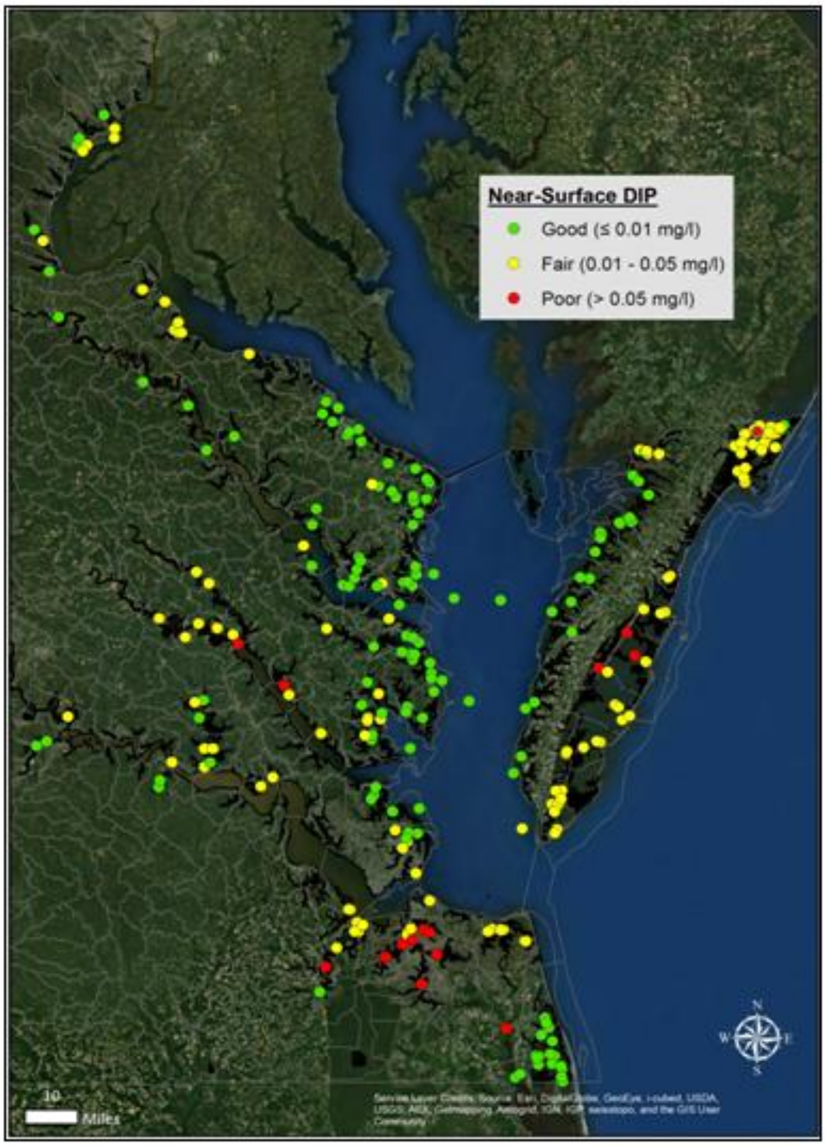


Surface DIN (mg/L)	
N	275
Max	1.269
99.24th %tile	0.500
99th %tile	0.448
95th %tile	0.164
91.93st %tile	0.100
90th %tile	0.094
75th %tile	0.030
UL 95% Median	0.015
Median	0.013
LL 95% Median	0.011
25th %tile	0.006
10th %tile	0.003
5th %tile	0.002
1st %tile	0.000
Min	0.000
Average	0.042
Std. Dev.	0.106
Std. Err.	0.006

Figure 4.5-3 Geographic and Statistical Distributions and Characterizations of 275 Dissolved Inorganic Nitrogen (DIN) Samples Collected at 273 Estuarine Sites from 2007 – 2012. Cutpoint criteria of 0.1 and 0.5 mg/L are from NCCA Reports I – IV (U.S. EPA 2001, 2004a, 2008, 2012).







Surface DIP (mg/L)	
N	275
Max	0.157
99th %tile	0.108
95th %tile	0.057
94.09th %tile	0.050
90th %tile	0.041
75th %tile	0.027
UL 95% Median	0.012
Median	0.010
LL 95% Median	0.008
49.44th %tile	0.010
25th %tile	0.005
10th %tile	0.003
5th %tile	0.002
1st %tile	0.001
Min	0.001
Average	0.019
Std. Dev.	0.021
Std. Err.	0.001

Figure 4.5-4 Geographic and Statistical Distributions and Characterizations of 273 Probabilistic Sites Based upon Near-Surface Dissolved Inorganic Phosphorus (DIP) Concentrations (2007 – 2010). Cutpoint criteria of 0.01 and 0.05 mg/L are from NCCA Reports I – IV (U.S. EPA 2001, 2004a, 2008, 2012).

Near-Bottom Dissolved Oxygen: Dissolved Oxygen (DO) profiles from near-surface (0.5 m) to near-bottom (0.5 m above sediment) were recorded during 274 of 275 site visits. Near-bottom DO concentrations are summarized here as one element in the NCCA Water Quality Index (WQI) for site classification, as well as in the Weight-of-Evidence (WOE) site assessment for Aquatic Life Designated Use (ALU), to be described below. Of 274 measured values, 227 (82.85%) were classified as "Good" based on near-bottom DO concentrations and NCCA criteria. An additional 45 sites (16.36%) were classified as "Fair" and only 2 sites (0.73%) were classified as "Poor."

The Chesapeake Bay Program (CBP) has established a year-around instantaneous minimum dissolved oxygen standard of 3.2 mg/L as being protective of fish and shellfish in open Bay waters. Thirteen (4.74 ± 2.53%) of the 274 observations would be characterized as "Poor" following this standard.

Twenty-one observations in the "Fair" and "Poor" classes (7.64 ± 3.15% of 274) constituted violations of Virginia's Instantaneous Minimum Saltwater Standard of 4.0 mg/L for Dissolved Oxygen, but a single observation of DO concentration at an individual ProbMon site is insufficient to classify that site as impaired for DO.

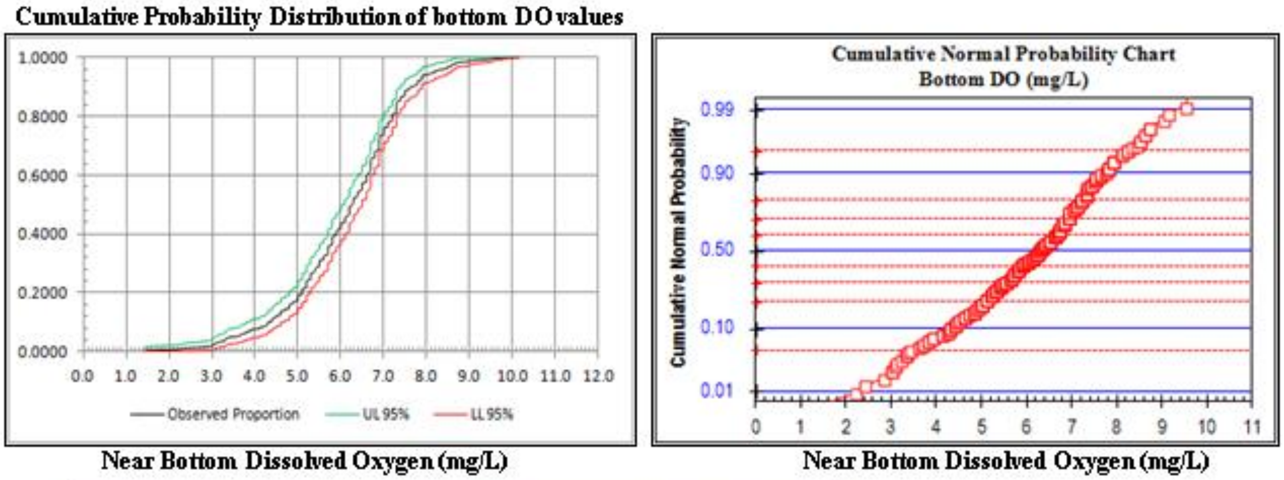
Virginia's estuarine waters would earn an overall score of "Good" under either the NCCA or CBP DO criteria, since under both the proportion of "Poor" sites was less than 5% of the total and more than 50% of the sites were in "Good" condition. Application of the more stringent (more protective) Virginia standard of 4.0 mg/L, would result in an overall score of "Fair," since the percentage of "Poor" sites (7.64 ± 3.15% of the total 274) would exceed 5%, even though the proportion of "Good" sites still exceeded 50%.

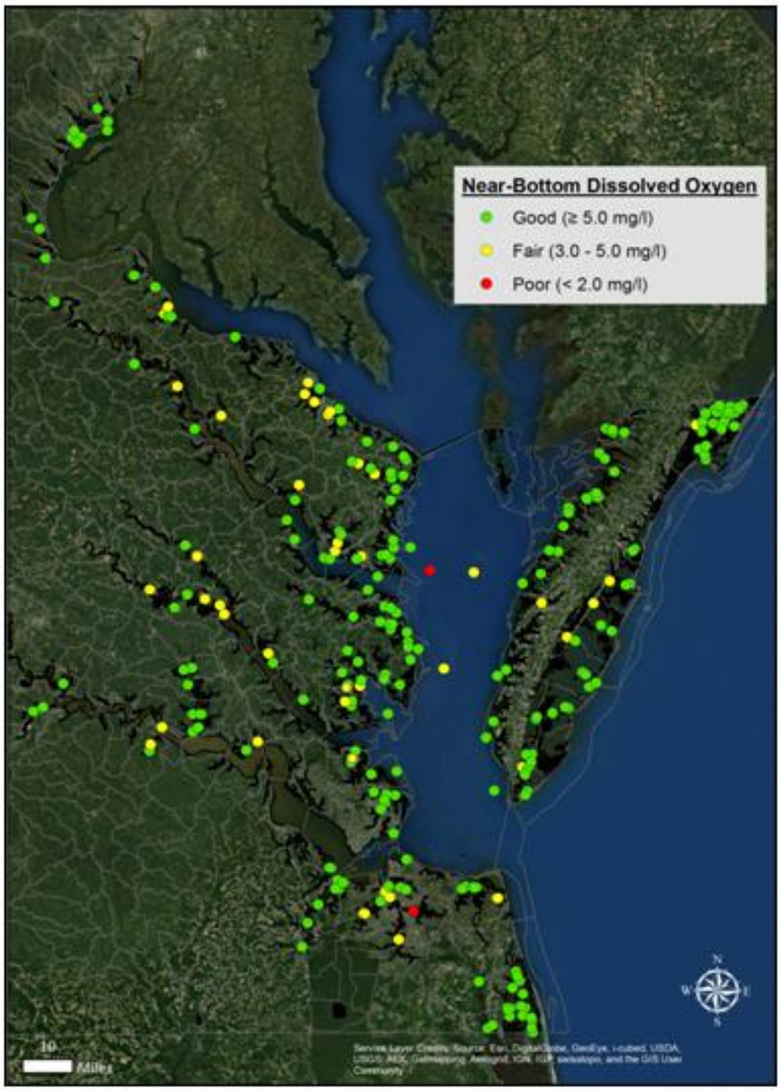
The geographic and statistical distributions of bottom DO measurements, evaluated by the NCCA criteria, are summarized in the map, table and charts of Figure 4.5-5. The symmetrical "S" shape of the cumulative probability distribution and the linear form of the cumulative normal probability chart indicate that the statistical distribution of bottom DO concentrations was essentially normal, with an average of 6.1 mg/L and a standard deviation of 1.4 mg/L. There is no indication that any strong regional or local influence depressed bottom dissolved oxygen concentrations within the estuarine area sampled under the Virginia state survey design.

Water Clarity: As pointed out earlier in this chapter, water clarity is considered an important element of water quality, but its inclusion in an integrated Water Quality Index (WQI) is more complex and controversial. Part of this controversy stems from the difficulty in differentiating the three classes of coastal waters as described for determining thresholds (cutpoints) for characterizing water clarity in previous NCCA Reports. Previous reports have classified broad estuarine water clarity regions as follows: (1) coastal waters with naturally high turbidity (Alabama, Louisiana, Mississippi, South Carolina, Georgia, and Delaware Bay), (2) coastal waters with normal turbidity (most of the United States), and (3) coastal waters that support SAV beds or have active programs for SAV restoration (Laguna Madre; the Big Bend region of Florida; the region from Tampa Bay to Florida Bay; the Indian River Lagoon; portions of Chesapeake Bay; Hawaii; American Samoa; Guam; Puerto Rico; and the U.S. Virgin Islands) (U.S. EPA, 2012). The ranges of water clarity used to classify sites into "Good", "Fair" or "Poor" categories within each of these aquatic resource classes are summarized in Table 4.5-5. The rational for classifying such broad geographic areas into a uniform or homogeneous expectation of water clarity is open to question. Clearly, the expectation of water clarity and the presence or absence of SAV would not be the same for local areas with disparate depths, exposure to high wave activity, with strong tidal currents, areas of varying bottom substrates, or in estuaries fed by tannin-stained blackwater streams. Shallower waters, more subject to wind and wave action and the re-suspension of bottom sediment, would be expected to have higher turbidities than deeper nearby waters.

Water clarity is also a function of the density of phytoplankton in the water column, and in this sense is a redundant characteristic that may be highly correlated with chlorophyll and nutrient concentrations in the water column. Its accurate measurement is also susceptible to variations in ambient light conditions – diffused light on cloudy or overcast days *versus* direct sunlight, and the angle of incident light at the water's surface. In addition, water clarity is extremely difficult to measure accurately at shallow sites.

In inland wetlands, streams and lakes the two meter depth is generally considered to be the maximum depth to which truly submerged aquatic plants normally occur (Cowardin et al., 1979). Floating or emergent aquatic vegetation may take root in deeper waters. EPA's Interstate Chesapeake Bay Program (CBP) has defined SAV zones for numerous segments within the Bay watershed as that portion of the segment extending from the shoreline out to a depth contour (isobath) of 2.0 meters, relative to mean low water (MLW) level, excluding certain segments where SAV was not expected to grow (Kemp et al., 2000). Water quality criteria (*e.g.*, water clarity) related to SAV growth and survival are only applied within these defined areas and during defined seasons. "For several SAV species (notably *Myriophyllum spicatum* and *Hydrilla verticillata*), maximum depth penetration might be greater than two meters, but it





Bottom DO (mg/L)	
N	274
Max	10.2
99th %tile	9.2
95th %tile	8.2
90th %tile	7.7
75th %tile	7.0
UL 95% Median	6.4
Median	6.3
LL 95% Median	6.1
25th %tile	5.3
17.34th %tile	5.0
10th %tile	4.3
5th %tile	3.5
1st %tile	2.3
0.63th %tile	2.0
Min	1.4
Average	6.1
Std. Dev.	1.4
Std. Err.	0.1

Figure 4.5-5 Geographic Distribution and Classification of 273 Probabilistic Estuarine Sites Based upon Near-Bottom Dissolved Oxygen Concentrations (2007 - 2012). Cutpoint criteria are from NCCA Reports I – IV (U.S. EPA 2001, 2004a, 2008, 2012). Twenty-one observations in the "Fair" and "Poor" classes (7.64 ± 3.15% of the total 274) constituted violations of Virginia's Instantaneous Minimum Saltwater Standard of 4.0 mg/L for Dissolved Oxygen.

was felt that this would be an exception. …" (Kemp et al., 2000). Criteria for excluding certain areas from the maps were based primarily on known historical SAV distributions, and on habitat areas exposed to high wave energy and (or) that have undergone physical modifications that prevented them from supporting SAV growth." Ironically, the same shallow water areas that potentially support SAV are the most susceptible to shoreline erosion and to the re-suspension of sediment by wave action. The presence of SAV in such shallow areas improves water clarity (and consequently water quality) by buffering wave action, thus enhancing the precipitation of suspended material, and reducing shoreline erosion and the re-suspension of previously deposited sediment. SAV and water clarity consequently interact with a positive feedback mechanism – the presence of SAV improves water clarity, improved water clarity enhances the growth of SAV, etc.

Table 4.5-5 NCCA Water Clarity Criteria Thresholds (cutpoints) Used to Classify Sites within Areas Potentially Supporting SAV, Areas of Normal Turbidity, and Areas of Naturally High Turbidity. All thresholds are defined in terms of Photosynthetically Active Radiation (PAR) available at a depth of 1.0 meter, relative to PAR availability at the water's surface.

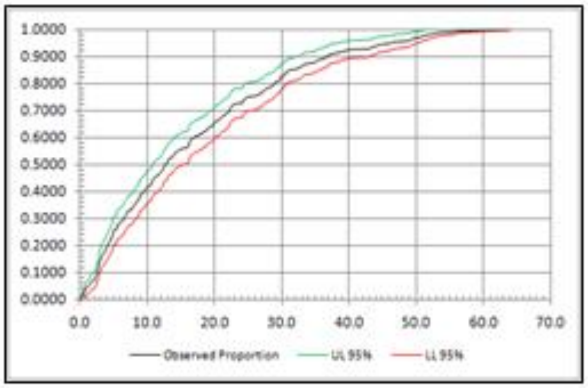
Water Clarity	Water Clarity Ranges Areas of SAV	Water Clarity Ranges Normal Turbidity	Water Clarity Ranges Naturally High
Good	≥ 40.0% @ 1.0 m	≥ 20.0% @ 1.0 m	≥ 10.0% @ 1.0 m
Fair	≥ 20 - < 40% @ 1.0 m	≥ 10 - < 20% @ 1.0 m	≥ 5 - < 10% @ 1.0 m
Poor	< 20.0% @ 1.0 m	< 10.0% @ 1.0 m	< 5.0% @ 1.0 m

The water clarity criteria established by the CBP for areas of SAV within Virginia's Chesapeake Bay watershed are published in Virginia's Water Quality Standards 9VAC25-260-185. In the following characterization, the scientifically derived CBP light availability (clarity) habitat types have been extended geographically, equated with local habitat types, and integrated with NCCA criteria where appropriate. This provided the application of similar criteria to define potential SAV areas in estuarine waters of coastal Delmarva and to the oligohaline waters of the Back Bay / North Landing River region (tributaries to Currituck Sound, NC) as were applied within the Chesapeake Bay watershed. Within the Bay watershed, sites that were within the designated SAV areas and had a depth equal to or less than 2.0 meters at the time of sampling were evaluated using the CBP criteria for defined SAV areas. Elsewhere, sites with depths less than or equal to 2.0 meters were considered potential SAV areas and were evaluated with the NCCA SAV criteria, unless they were impacted by strong wave action or strong tidal currents. Such determinations were made using map reconnaissance, comments from site field sheets, and the evaluation of substrate structure. Sandy substrates with very low fine particle concentrations (*e.g.*, ≥ 95% sand) were considered to be characteristic of such impacted sites. Sites with deeper waters (>2.0 m) were evaluated as areas of normal turbidity, although why coastal Delmarva waters of Virginia should be considered less turbid (normal) than coastal South Carolina and Georgia waters (naturally high) is a valid and unanswered question.

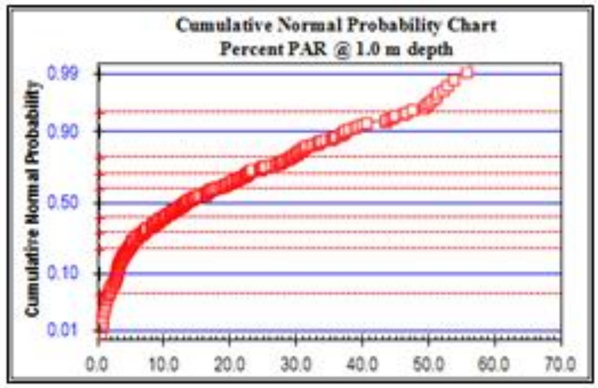
The geographic distribution and characterization of the 273 sites, based on the integrated, mixed water clarity criteria described above, are illustrated in the map of Figure 4.5-6. The statistical distribution of "Percent PAR @ 1.0 m depth" in the table of Figure 4.5-6 is not classified or color-coded because thresholds for characterizations ("Good", "Fair", etc.) vary with location, salinity, depth, etc. It appears, from the cumulative normal probability chart that the clarity values above the median of 12.9% PAR @ 1.0 m are approximately normally distributed. The majority of the highest water clarity sites occur in the Chesapeake Bay mainstem and its embayments.

Virginia's estuarine waters received an overall score of "Poor" for water clarity because more than 25% of the individual sites were scored as "Poor". This score may be worse than warranted, because many sites that were individually scored as "Poor" actually fell within CBP SAV segments that, based on several years of ambient monitoring, were evaluated as meeting SAV growth goals for DEQ's 2012 Integrated 305(b)/303(d) Water Quality Report (DEQ-WQA. 2012). This was especially evident in the upper tidal Potomac River, the Rappahannock, Mattaponi and Pamunkey Rivers, and tributaries to the lower tidal James River (refer to Figure 4.5-6). An additional factor is that DEQ's state design targets smaller tributaries and embayments (generally shallower waters) where sediment laden storm runoff waters are more prevalent and re-suspension of existing sediment is more common, and normally excludes the open bay and lower, broader major tidal tributaries where water clarity would generally be better.

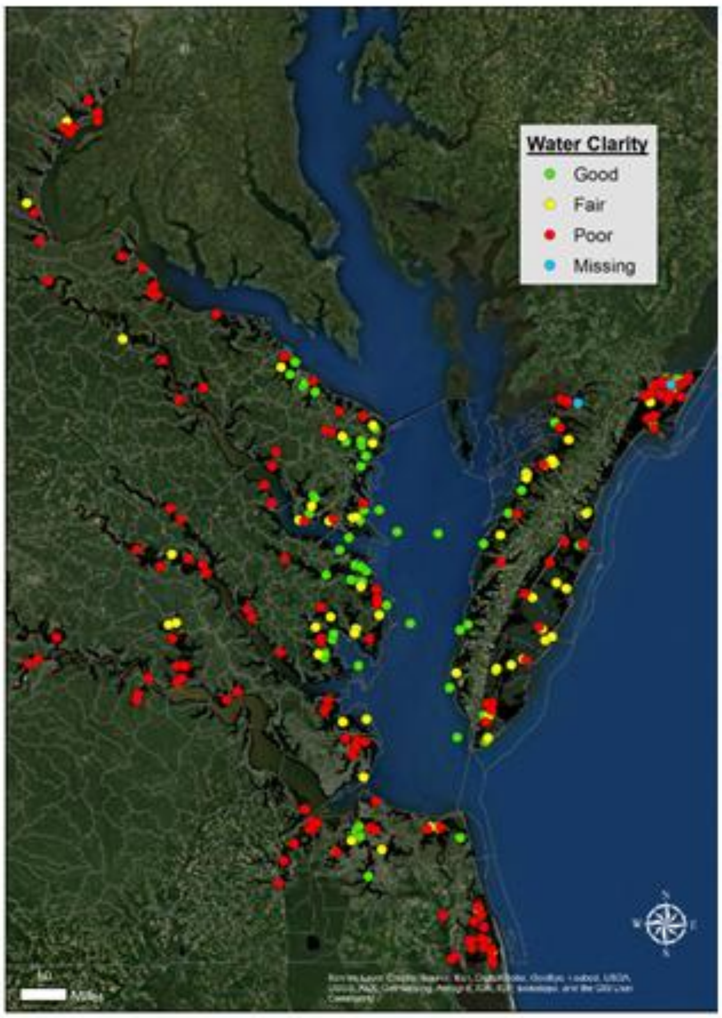
Cumulative Probability Distribution of % PAR @ 1.0 m



Water Clarity in % available PAR @ 1.0 m depth



Water Clarity in % available PAR @ 1.0 m depth



Water Clarity %PAR @ 1.0 m	
N	273
Max	64.06%
99th %tile	53.95%
95th %tile	46.10%
90th %tile	36.86%
75th %tile	25.05%
UL 95% Median	14.82%
Median	12.91%
LL 95% Median	11.00%
25th %tile	4.97%
10th %tile	2.66%
5th %tile	1.44%
1st %tile	0.42%
Min	0.005%
Average	16.84%
Std. Dev.	13.96%
Std. Err.	0.84%

Figure 4.5-6 Geographic and Statistical Distributions and Characterizations of 271 Probabilistic Estuarine Sites based on Water Clarity. Characterizations were based on integrated, mixed water clarity criteria from the Interstate Chesapeake Bay Program (CBP) and the National Coastal Condition Assessment (NCCA) surveys. See Table 4.5-11 and associated text for a more detailed explanation. The statistical distribution of "Percent PAR @ 1.0 m depth" is not classified or color-coded because criteria for characterizations ("Good", "Fair", etc.) vary with location, salinity, depth, etc. * Two sites (blue symbols – Pocomoke and Chincoteague) were not characterized because water clarity data were not available.

Water Quality Index (WQI): As described above, under General Considerations of the Water Quality section, the first four NCCA Reports (U.S. EPA 2001, 2004a, 2008, 2012) integrated five water quality metrics (Chl-a, DIN, DIP, bottom DO and water clarity) into a general Water Quality Index (WQI) for site characteizations. Discussions early in 2013, related to the Fifth NCCA Report ("Progress Update – National Webinar – National Coastal Condition Assessment." U.S. Environmental Protection Agency - 14 January 2013), raised the question of whether or not the water clarity metric should be included in this index, not only because of the difficulty in establishing appropriate local criteria, but also because water quality is such an ephemeral characteristic of the local water bodies (*i.e.*, varies from hour to hour, minute to minute). The final decision on NCCA Report V, in late 2013, was to include the water clarity metric in the WQI for the fifth report, but the controversy continues. For this reason, calculations of the Water Quality Index in the current chapter have been carried out both including and excluding the Water Clarity metric. Table 4.5-6 (A & B), below, summarizes site-specific WQI characterizations including the integrated, mixed criteria water clarity metric (A) and excluding the water clarity metric (B). It is evident from comparison of the two tables (A & B) that the the contribution of the water clarity metric has a overpowering influence on individual site characterizations. Removal of the single water clarity metric increased the number of "Good" characterizations for sites from 44 (16.0%) to 119 (43.3%) and decreased the number of "Poor" characterizations from 48 (17.5%) to 4 (1.5%). The result of these differences, however, would not be enough to change Virginia's overall characterization based on the WQI. The overall characterization of Virginia's estuarine waters based on the WQI would be "Fair", since the proportion of sites characterized as "Poor" was less than 20% and the proportion of sites characterized as "Good" was less than 50% under both five-metric and four-metric WQI calculations. See Table 4.5-7 for scoring thresholds of WQI regional characterizations.

Table 4.5-6 Water Quality Index (WQI) Characterizations of 273 Sites based on 275 Visits Calculated with (A) IWQ_5 - Five Metrics including Mixed Water Clarity Criteria and with (B) IWQ_4 - Four Metrics excluding Water Clarity.

A

IWQ_5 - Five Metrics - Mixed Clarity Criteria

Water Quality Index	Water Quality Metric Range	Observed Sites N (% ± CI 0.95)
Good	≤ 1 Fair, No Poor	44 (16.00 ± 4.35%)
Fair	1 Poor, or ≥ 2 Fair	183 (66.55 ± 5.60%)
Poor	≥ 2 Poor	48 (17.45 ± 4.51%)
		275 (100.00%)

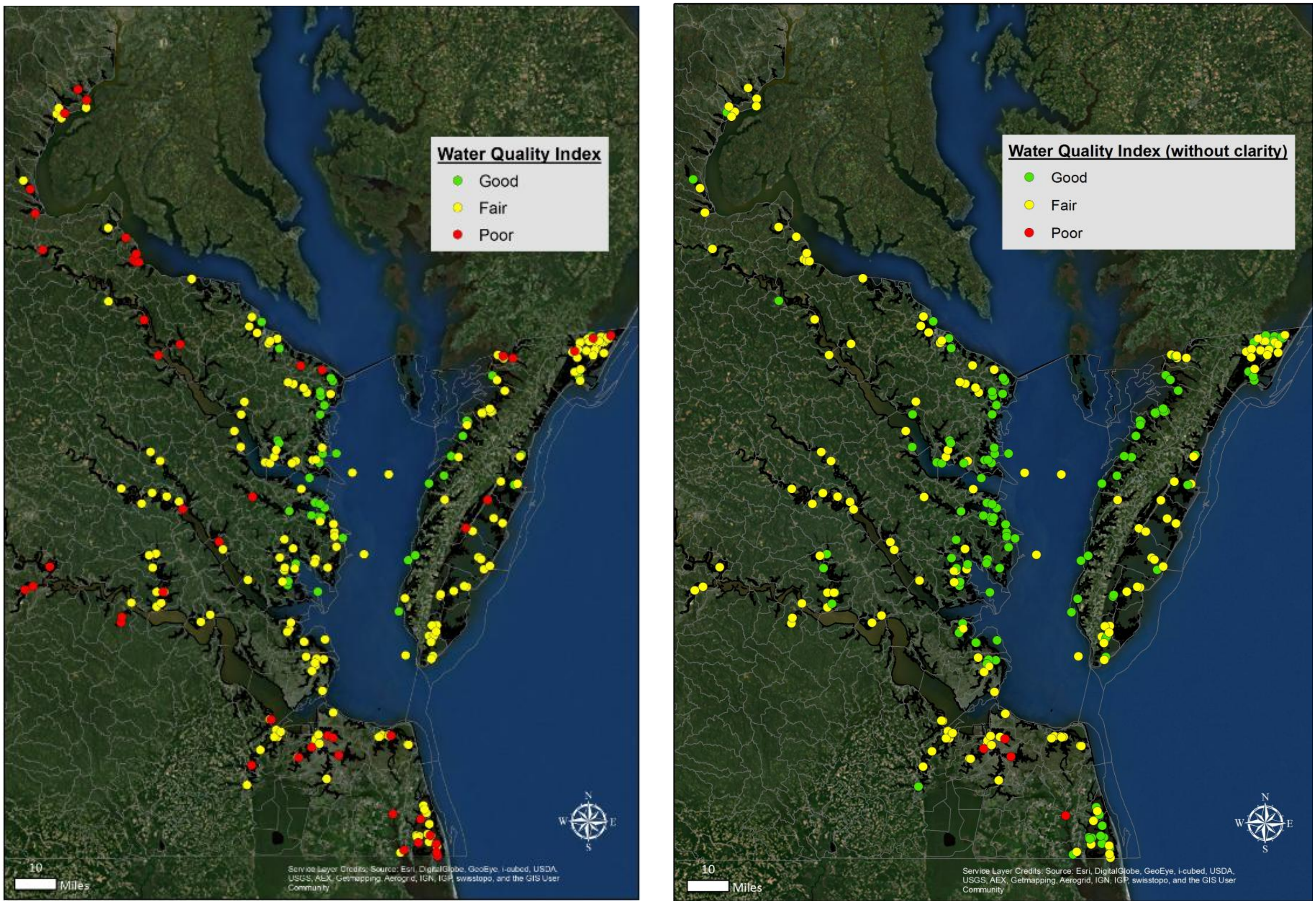
B

IWQ_4 - Four Metrics - no Clarity

Water Quality Index	Water Quality Metric Range	Observed Sites N (% ± CI 0.95)
Good	≤ 1 Fair, No Poor	119 (43.27 ± 5.88%)
Fair	1 Poor, or ≥ 2 Fair	152 (55.27 ± 5.90%)
Poor	≥ 2 Poor	4 (1.45 ± 1.42%)
		275 (100.00%)

Table 4.5-7 Thresholds for Determining the Water Quality Index (WQI) Rating by Region (from NCCA Report IV, U.S. EPA, 2012).

Rating	Cutpoints
Good	Less than 10% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.
Fair	10% to 20% of the coastal area is in poor condition, or 50% or less of the coastal area is in good condition.
Poor	More than 20% of the coastal area is in poor condition.



A – With Clarity **B – Withoput Clarity**

Figure 4.5-7 Geographic Distribution and Characterizations of 273 Probabilistic Estuarine Sites based on the Water Quality Index (WQI), A - Calculated with five metrics, including the Integrated, Mixed Criteria Water Clarity Metric and B - with four metrics, excluding the Integrated, Mixed Criteria Water Clarity Metric. The regional characterization of Virginia's estuarine waters would be rated "Fair" under either WQI, since the proportion of "Poor" sites never exceeded 20% and the proportion of "Good" sites never exceeded 50% under either system.

Other Water Quality Measures: In DEQ's state design Estuarine Probabilistic Monitoring Program the agency added on several water column parameters that have not traditionally been required for NCCA surveys. The first of these consisted of near-surface bacterial monitoring and the second consisted of the near-surface sampling and analysis of trace metals (both dissolved and total). The results from these efforts are discussed in the following sections.

Bacteria: DEQ sampled bacteria from near the water's surface using standard protocols described in the agency's QAPP and SOP. Samples were collected directly into sterile 125 mL containers and were shipped on ice via overnight courier service to the state laboratory (DCLS) in Richmond for analysis under the Parameter Group Code MFEE. This parameter group code indicates that the membrane filtration method is applied for identification and enumeration of colony forming units (cfu) per deciliter (one dL = 100 mL) of three groups of bacteria: (1) *Escherichia coli* (*E. coli*), (2) bacteria of the genus *Enterococcus* (enterococci), and (3) fecal coliform bacteria. Virginia Code specifies instantaneous maximum Water Quality Standards for primary contact recreational use of freshwater (including tidal fresh) of 235 cfu/dL of *E. coli* and for transitional and saltwater of 104 cfu/dL of enterococci. The Virginia Department of Health uses concentrations of fecal coliform bacteria to evaluate estuarine waters for shellfish harvest and consumption, but fecal coliform results will not be discussed here. For scoring individual sites on the basis of bacterial contamination, the salinity at the time of sampling was used to classify the site salinity zone (refer to Table 4.5-1 for salinity zone criteria), and then the measured concentration of the appropriate bacterial group was evaluated (*E. coli* in tidal fresh and enterococci in oligohaline, mesohaline, polyhaline and euhaline). If the appropriate bacterial group was below detection limits the site was characterized as "Good". If the appropriate bacterial group was at or in excess of the corresponding instantaneous maximum standard concentration, the site was characterized as "Poor". If the appropriate bacterial concentration was measurable and was below the corresponding standard the site was characterized as "Fair".

The majority of the 271 sites (196 = 71.8%) were characterized as "Good", and only 17 (6.23%) were characterized as "Poor" for bacterial contamination. The geographic distribution and characterizations of the sites are illustrated in the map of Figure 4.5-8. No cumulative frequency distributions or statistical summaries are presented for bacteria, because the bacterial counts constitute a discontinuous variable with varying intervals between values. Also, the integrated results are from two different groups of bacteria in different habitats, each with different water quality standards and threshold criteria.

EPA's National Coastal Condition Assessment Reports (U.S. EPA 2001, 2004a, 2008, 2012) do not provide criteria for site characterizations based on bacterial contamination, nor are thresholds available for regional characterizations. Best professional judgment would suggest that because almost 72% of the samples contained no detectable bacteria of interest, and bacterial water quality standards were exceeded in less than 10% of the samples, the overall condition of Virginia's estuarine waters based on bacterial contamination was "Fair" to "Good"!

Dissolved Trace Metals in the Water Column: Between 2008 and 2011, DEQ's Estuarine Probabilistic Monitoring (ProbMon) Program collected clean dissolved and total trace metals samples from near surface waters (0.3 m depth) at 182 probabilistic estuarine sites. All of these trace metals samples were analyzed at the Division of Consolidated Laboratory Services (DCLS) of the Virginia Department of General Services (DGS) in Richmond. Only dissolved metals results are discussed here, due to the fact that all EPA criteria and the resultant Virginia water quality standards for metals are based on dissolved concentrations. Chronic Saltwater Standard Quotients (CSq) were calculated by dividing the observed dissolved concentrations of each metal by its chronic saltwater standard or, in the case of Vanadium, by its EPA-recommended chronic saltwater benchmark. Virginia does not yet have a saltwater standard for Vanadium.

Chronic Standard quotient (CSq) = Observed dissolved concentration / chronic saltwater standard
e.g., for Copper: CSq_{-Cu} = μg/L dissolved Cu observed / Chronic saltwater standard for Cu (6.0 μg/L)

Ten of the 182 sites were in tidal freshwater and their quotients were calculated using chronic freshwater standards. In either case, quotients equal to or greater than 1.0 indicate that a standard or recommended criterion has been violated (i.e., equaled or exceeded).

Of the 182 sites, 130 were within tidal portions of the Chesapeake Bay watershed. Within the Chesapeake Bay drainage, no exceedances of chronic standards were observed for any of the toxic metals evaluated (As, Cd, Cu, Pb, Hg, Ni, Se, and Zn). Vanadium was added to the analyses beginning in 2010, and no exceedances were observed of EPA's recommended saltwater benchmark for Vanadium (50 μg/L - http://www.epa.gov/bpspill/water-benchmarks.html) among the 77 samples evaluated since that time. Among 1532 parameter by parameter

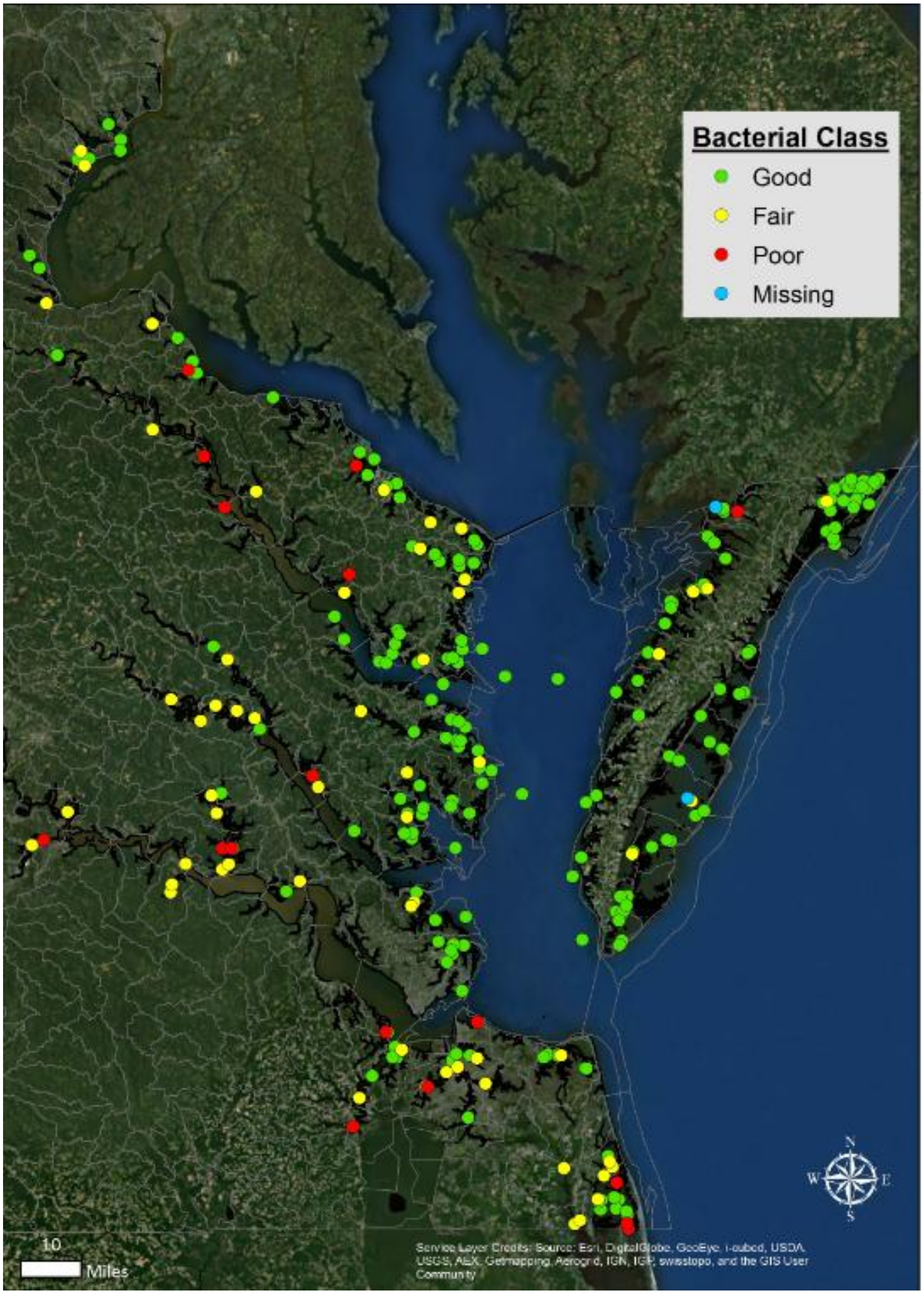


Figure 4.5-8 Geographic Distributions and Characterizations of 271 Probabilistic Estuarine Sites based on Bacterial Contamination. No cumulative frequency distributions or statistical summaries are presented for bacteria, because the bacterial counts constitute a discontinuous variable with varying intervals between values. Also, the integrated results are from two different groups of bacteria in different habitats, each with different water quality standards and threshold criteria. Bacterial samples from two sites (blue missing symbols) were lost, broken, or became contaminated in transit. Red symbols represent sites that violated the appropriate instantaneous maximum water quality standard at the time of sampling.

comparisons performed at 182 sites statewide (including Vanadium at 77 sites) only one exceedance of a chronic saltwater standard was observed. Dissolved Nickel (Ni) exceeded its chronic saltwater quality standard by a factor of 2.16 at a single site - DEQ station 7CCHT002.66, located off Cockle Point in Chincoteague Bay, near a highly developed residential shoreline with numerous private boating facilities.

The statistical distributions of the chronic standard quotients are summarized in Table 4.5-8 and Figure 4.5-9 below. The single dissolved Nickel exceedance is indicated with red font in the table. Note that only 77 sites were evaluated for Vanadium, and that a single site lacked a Mercury sample. With the exception of the single exceedance for Nickel, no dissolved metal even approached its chronic saltwater standard. The only other individual metal CSq values that exceeded 0.500 were for dissolved Copper. Copper was also the only metal for which the 99th percentile of the sample CSq distribution exceeded a value of 0.500. The maximum observed CSq of 0.653 for Copper is also identified in red font in Table 4.5-8 below, even though it does not represent a violation of the chronic standard.

In order to integrate the degree of contamination at each site across all dissolved metals, the arithmetic means of the CSq values were calculated, by site, for all quotients (As, Cd, Cu, Pb, Hg, Ni, Se, and Zn) except Vanadium. The statistical distributions of the results for individual metals are summarized in the table of Mean CSq Values (Table 4.5-8) and in Figure 4.5-9, below. Using the arithmetic mean CSq values, most stations in the upper quartile were characterized as fair and were assigned pale yellow symbols in the table and on the map of Figure 4.5-9, below. Three exceptions, in the "Poor" class, are discussed below. The cumulative probability distribution and the cumulative normal probability chart in Figure 4.5-9 suggest that the mean CSq values for sites with concentrations below the 75th percentile (mean CSq < 0.0392) of the distribution are essentially normally distributed. They score "Good" to "Excellent" in the rating scale used for site characterizations. Mean CSq values above the 75th percentile and below the approximate 98th percentile (0.0933) diverge from the lower distribution, and were characterized as "Fair". On the map, the single site with a Nickel exceedance (7CCHT002.66 - CSq_{-Ni} = 2.160, mean CSq = 0.2897) and the two sites with Copper CSq-cu values above 0.5000, *i.e.*, 0.653 and 0.582 (stations 7BSWB001.59 – mean CSq = 0.106 and 7-OLD000.56 – mean CSq = 0.0978, respectively - see description of Figure 4.5-9) are identified with red symbols. Sites in the third quartile (0.029 ≤ mean CSq ≤ 0.039) were characterized as good and identified with pale green symbols, and sites at or below the 50th percentile (median CSq = 0.029) were characterized as excellent and assigned a bright green symbol. The quartile thresholds used for this characterization are arbitrary, since there are no published studies known to the author that quantify the effects of the mean CSq values on benthic communities or pelagic organisms.

As indicated above, dissolved metal exceedances of chronic water quality standards were very rare among the 182 probabilistic sites evaluated (0.55% of sites, 0.065% of individual CSq values). Based on this observed distribution of chronic standard quotients for individual metals and the distribution of Mean CSq values among the 182 sites (only three sites with Mean CSq above 0.0933 – 1.65%), Virginia's estuarine waters probably rate an overall characterization of "Good" for dissolved trace metals. A very similar result was observed for Virginia's freshwaters in a study carried out by the Free-running Freshwater Probabilistic Monitoring Program since 2008. Dissolved concentrations of trace metals appear to rapidly enter into equilibrium with the surrounding substrate, and the occasional excursions into higher concentrations are only apparent very near to known input sources.

Dissolved metals concentrations did not correlate highly with the mean ERMq values for the underlying sediment (r^2 = 0.056 - see the more detailed discussion below, in the section on sediment contamination) or with benthic IBI scores (r^2 = 0.027). The DEQ station (7CCHT002.66) in Chincoteague Bay, where the dissolved Ni concentration was more than double the chronic saltwater standard, had only 4.4 mg Ni / Kg of dry sediment. This is only 0.085 of its Effects Range Median (ERM) and 0.221 of its Effects Range Low (ERL) sediment screening values. The water was only 1.8 meters deep at the site, so filter-feeding benthos would be exposed to essentially the same dissolved concentrations as those observed in the water column sample. General sediment quality at the site was rated "Good" based on sediment toxicity, sediment contamination, and total organic carbon content. Water quality, based on nutrient, chlorophyll-a, and dissolved oxygen concentrations was rated as "Good" and benthic health was rated "Good" by three separate benthic indices!

Among seven sites in the Elizabeth River system, where sediment contamination by metals is known to be high, the maximum CSq for dissolved Ni was only 0.106. The maximum observed CSq for any dissolved metal in the Elizabeth river system was 0.350 (for Copper). The copper concentration in the sediment at that same site (2CELI004.12) was 52.50 mg Cu / dry kg (0.194 of its ERM and 1.544 of its ERL sediment screening values).

Table 4.5-8 Summary of the Statistical Distributions of Chronic Standard Quotients (CSq) for each Toxic Dissolved Trace Metal Evaluated. The single exceedance (dissolved Nickel) observed among 1532 comparisons is indicated in red font, as are the 99th percentile and maximum observed CSq of 0.653 for Copper. Two sites that had CSq greater than 0.500 for Copper are identified with red symbols on the Map of Figure 4.5-9.

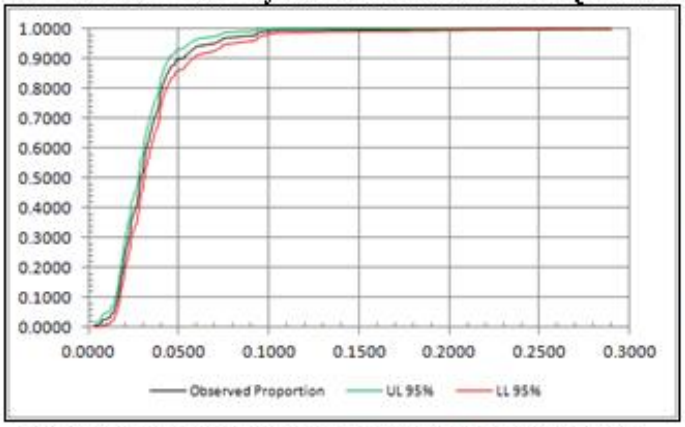
	Analyte	Arsenic (As)	Cadmium (Cd)	Copper (Cu)	Lead (Pb)	Mercury (Hg)	Nickel (Ni) [1]	Selenium (Se)	Vanadium (V) [2]	Zinc (Zn)
	Status / Units	dissolved, µg/L	dissolved, µg/L	dissolved, µg/L	dissolved, µg/L	dissolved, ng/L	dissolved, µg/L	dissolved, µg/L	dissolved, µg/L	dissolved, µg/L
	Chronic saltwater standard	36 µg/L	8.8 µg/L	6.0 µg/L	9.3 µg/L	940 ng/L	8.2 µg/L	71.0 µg/L	50.0 µg/L	81.00
	Method detection limit (MDL)	0.04 µg/L	0.1 µg/L	0.1 µg/L	0.1 µg/L	0.7 ng/L	0.2 µg/L	0.07 µg/L	0.7 µg/L	0.5 µg/L
	Number of Observations	182	182	182	182	181	182	182	77	182
	Number < MDL	0	165	3	170	67	5	82	6	27
	Percent < MDL	0.0%	90.7%	1.6%	93.4%	37.0%	2.7%	45.1%	7.8%	14.8%
Chronic Standard / Criterion Quotients	Max	0.333	0.145	0.653	0.108	0.0636	2.160	0.126	0.174	0.296
	99th %tile	0.127	0.138	0.501	0.030	0.0487	0.209	0.117	0.170	0.233
	95th %tile	0.058	0.123	0.231	0.011	0.0173	0.122	0.009	0.150	0.102
	90th %tile	0.049	0.031	0.167	0.006	0.0081	0.102	0.003	0.137	0.078
	75th %tile	0.038	0.003	0.127	0.002	0.0024	0.083	0.002	0.050	0.040
	UL 95% Median	0.027	0.000	0.085	0.001	0.0013	0.069	0.001	0.039	0.024
	Median	0.024	0.000	0.076	0.001	0.0010	0.065	0.001	0.035	0.020
	LL 95% Median	0.021	0.000	0.067	0.001	0.0008	0.061	0.001	0.031	0.017
	25th %tile	0.015	0.000	0.050	0.000	0.0004	0.049	0.000	0.026	0.009
	10th %tile	0.008	0.000	0.032	0.000	0.0001	0.039	0.000	0.016	0.001
	5th %tile	0.005	0.000	0.019	0.000	0.0000	0.032	0.000	0.010	0.000
	1st %tile	0.003	0.000	0.008	0.000	0.0000	0.019	0.000	0.004	0.000
	Min	0.003	0.000	0.000	0.000	0.0000	0.000	0.000	0.002	0.000
	Mean	0.030	0.011	0.100	0.003	0.0036	0.081	0.006	0.050	0.034
	Std. Dev.	0.036	0.032	0.090	0.010	0.0082	0.158	0.021	0.042	0.044
	Std. Err.	0.003	0.002	0.007	0.001	0.0006	0.012	0.002	0.005	0.003
	Analyte	Arsenic (As)	Cadmium (Cd)	Copper (Cu)	Lead (Pb)	Mercury (Hg)	Nickel (Ni)	Selenium (Se)	Vanadium (V)*	Zinc (Zn)
	Number/percent attaining or exceeding the Chronic Standard	0 0.0 %	0 0.0 %	0 0.0 %	0 0.0 %	0 0.0 %	1 0.55 ± 1.08% [3]	0 0.0 %	0 0.0 %	0 0.0 %

[1] Among 1532 dissolved metals evaluations in estuarine waters, a single dissoloved Nickel concentration exceeded its chronic saltwater standard by a factor of 2.16. The site was located off Cockle Point in Chincoteague Bay, near a highly developed residential shoreline with numerous private and commercial boating facilities.

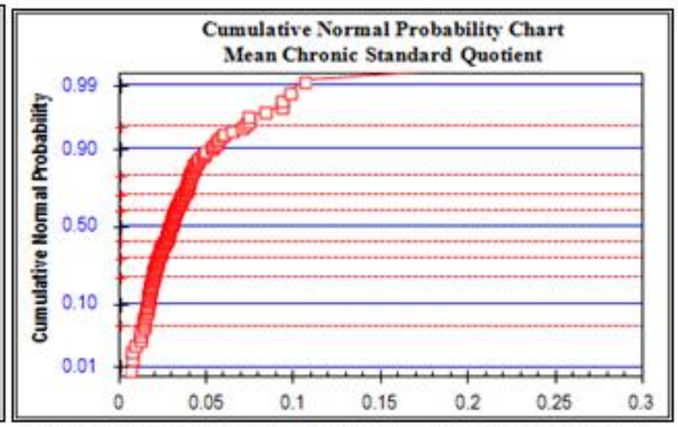
[2] Vanadium was added to the parameter suite in 2010 as a result of the Deep Horizon petrolrum release in the Gulf of Mexico. Virginia currently does not have a saltwater standard for Vanadium, but in 2010 the US EPA posted a recommended chronic criterion of 50 µg/L for Vanadium on its Webpages related to the Deep Horizon release.

[3] Observed percentage plus or minus its 95% confidence limits (Obs. ± $t_{\alpha=.05}$ Std. Dev.).

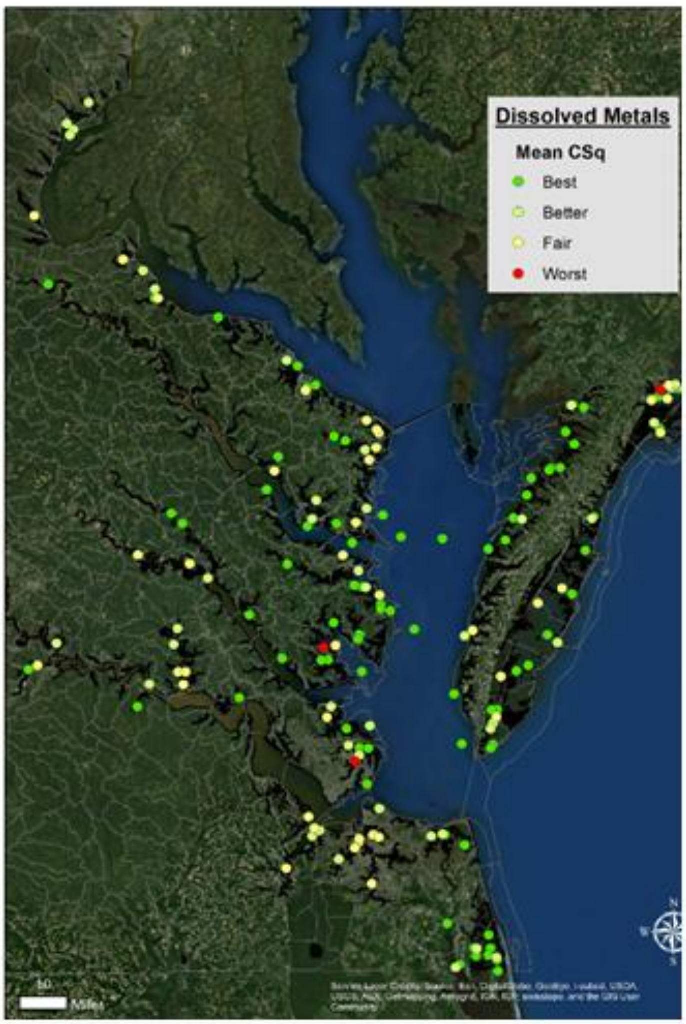
Cumulative Probability Distribution of Mean CS Quotient



Mean Chronic Standard Quotient for Dissolved Metals



Mean Chronic Standard Quotient for Dissolved Metals



Site Characterization Classes	Mean Chronic Standard Quotient (mCSq) Ranges	Observed Classes N (%)
Best	≤ 0.0288	91 (50.00 ± 7.31%)
Better	0.0289 - 0.0391	45 (24.73 ± 6.31%)
Fair	0.0392 - 0.0977	43 (23.63 ± 6.21%)
Worst	$CSq_{-Ni} > 1.0$ or $CSq_{-Cu} > 0.5$	3 (1.65 ± 1.86%)
		182 (100.00%)

Mean Quotients Exclude Vanadium!	Mean Chronic Standard Quotient (m-CSq)
Max	0.2897
99th %tile	0.0995
95th %tile	0.0698
90th %tile	0.0526
75th %tile	0.0392
UL 95% Median	0.0310
Median	0.0289
LL 95% Median	0.0267
25th %tile	0.0206
10th %tile	0.0165
5th %tile	0.0141
1st %tile	0.0070
Min	0.0032
Mean	0.0335
Std. Dev.	0.0254
Std. Err.	0.0019

Figure 4.5-9 Geographic and Statistical Distributions of Clean Dissolved Metals - Mean Chronic Standard Quotients. Quotients were calculated for all metals with chronic saltwater standards (As, Cd, Cu, Pb, Hg, Ni, Se, and Zn) – Vanadium only has an EPA-assigned chronic benchmark. The single site with the exceedance of the Nickel chronic standard is identified with a red symbol in Chincoteague Bay. Two sites with mean CSq-cu exceeding 0.5 are also identified with red symbols: one in the Back River, Southwest Branch and one in Oldhouse Creek, Ware River tributary. These three sites also have the highest mean CSq values across all metals with saltwater chronic standards: 0.2897, 0.1065 and 0.0978, respectively. Color coding thresholds are arbitrary and are estimated from the Cumulative Normal Probability Chart in the figure.

As a result of the generally low dissolved trace metal concentrations observed in estuarine waters, the sampling of dissolved metals in this program was suspended after 2011, and the resources were transferred to the Fish Tissue and Sediment Monitoring Program, which had been suspended since 2009 for lack of resources.

Sediment Quality

General Considerations: The NCCA Program has, since its inception, considered three sediment characteristics important in the evaluation of sediment quality: (1) sediment toxicity, (2) sediment chemical contamination and (3) sediment total organic carbon (TOC) content. Each of these characteristics has been evaluated separately in NCCA Reports, and the three evaluations were subsequently integrated into a Sediment Quality Index (SQI). In the sections that follow, each of these three sediment characteristics has been evaluated first using the traditional NCCA guidelines, followed by characterizations using other indices available in the literature. It is hoped that the alternative characterizations presented here will help better represent the conditions of Virginia's estuarine waters and perhaps provide supporting documentation for the reevaluation of NCCA characterization methods and threshold criteria in future National Coastal Condition Reports.

Sediment Toxicity: Sediment toxicity (SedTox) has been included as one element of sediment quality since the inception of the Coastal 2000 Initiative. Toxicity test design has been of a standard structure, with five test replicates of 20 test organisms each for each sediment sample, and with the same structure for control sediment (U.S. EPA, 1994). The endpoint of the acute toxicity tests is mortality of the test organism. SedTox results have been expressed as control-corrected survivorship (C-CS) of burrowing marine amphipods following ten-day, static, acute toxicity tests in an estuarine sediment matrix. From 2000 through 2009 both the NCA and the DEQ state designed Estuarine ProbMon Programs utilized *Ampelisca abdita* as the test organism. Prior to 2010, the use of *A. abdita* by the NCA Program had been criticized because the organism was considered to be too insensitive to sediment contamination. DEQ maintained use of the same species to preserve comparability of test results with the national program. Beginning with the 2010 National Aquatic Resources Survey/National Coastal Condition Assessment (NARS/NCCA), a new test organism, *Leptocheirus plumulosus,* was employed. DEQ has also employed *L. plumulosus* in its state design program since 2010. At two 2010 sites, sediment samples from return visits resulted in the same final classifications ("Good" in all cases). At one other NCCA site in 2010 the sandy sediment was too compacted to collect SedTox samples with the petite Ponar grabs employed by DEQ.

In National Coastal Condition Reports I – IV (U.S. EPA, 2001, 2004, 2008, 2012) EPA classified the results of SedTox tests as either "Good" (C-CS ≥ 80%) or "Poor" (C-CS < 80%), with no intermediate class of "Fair" defined. Mortality greater than 20% (C-CS < 80%) was considered to be biologically or ecologically meaningful, without comparisons with controls to evaluate the statistical significance of differences. For the purpose of the current IR, an additional intermediate class of "Fair" has been defined for those sites with transitional results where C-CS ≥ 80% but a statistical test (TOXSTAT - West and Gulley, 1996) revealed a statistically significant difference ($p \leq 0.05$) from controls, or where C-CS was < 80% but statistical significance from controls could not be verified ($p > 0.05$).

The characterization of the sites using both these criteria is summarized in Figure 4.5-10, below, and the geographic distributions of results are illustrated in Figure 4.5-11, on the following page. Applying the original NCCA criteria, 258 results from 274 tests (94.16 ± 2.79%) were characterized as "Good" for sediment toxicity, and 16 results (5.84 ± 2.79%) were characterized as "Poor." The NCCA cutpoint for a "Good" regional characterization is "less than 5% of the coastal area is (sites are) in poor condition," and the criterion for a regional characterization of "Poor" is that "5% or more of the coastal area is in poor condition." Since the "Poor" characterizations under NCCA criteria include 5.85% of the 274 tested samples, the result would be a "Poor" characterization for an overall classification. However, the 95% confidence interval on the percent "Poor" (5.84 ± 2.79%) includes values less than 5%, and leaves some doubt about the validity of the "Poor" characterization.

In the numerical distribution of 274 test results using the modified DEQ classification, two hundred fifty-two sites (92.0 ± 3.2%) revealed no significant sediment toxicity, and consequently were classified as "Good." Nine sites (3.3 ± 2.1%) were classified as "Fair", and 13 sites (4.7 ± 2.5%) were classified as "Poor." The nine "Fair" sites were derived from six "Good" sites and three "Poor" sites in the NCCA classification. The single missing observation common to both classifications represented less than 1.0% of the total 275 site visits (completeness = 99.6 ± 0.7%). Following the adapted DEQ criteria, Virginia's estuarine waters as a whole would have slightly less than 5% of the sites in "Poor" condition (4.7 ± 2.5%). This differs only slightly from the NCCA results, and the 95% confidence interval also includes values both below and above the "Poor" cutpoint. Both characterizations lack 95% confidence in either a "Poor" or in a "Good" classification, which would support the choice of a "Fair" (intermediate) characterization for the estuarine area as a whole.

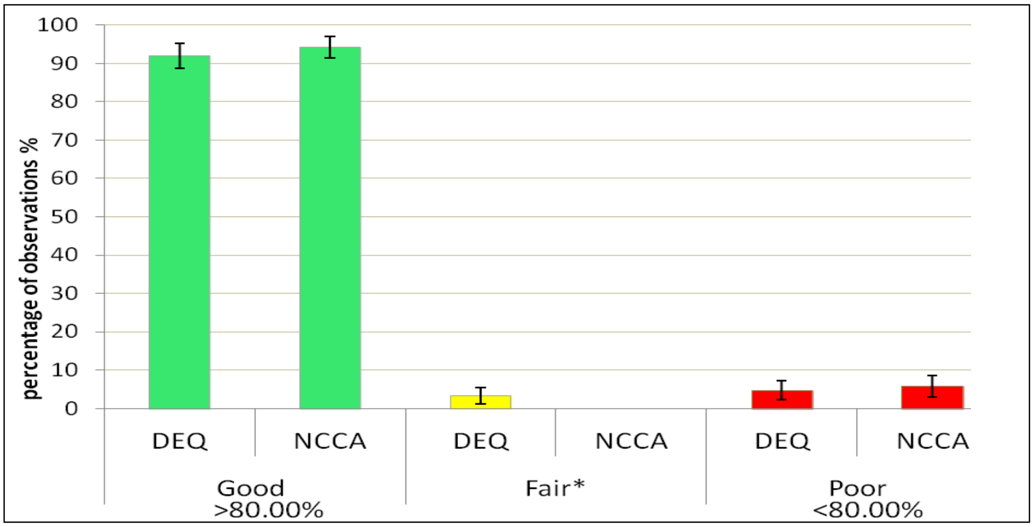


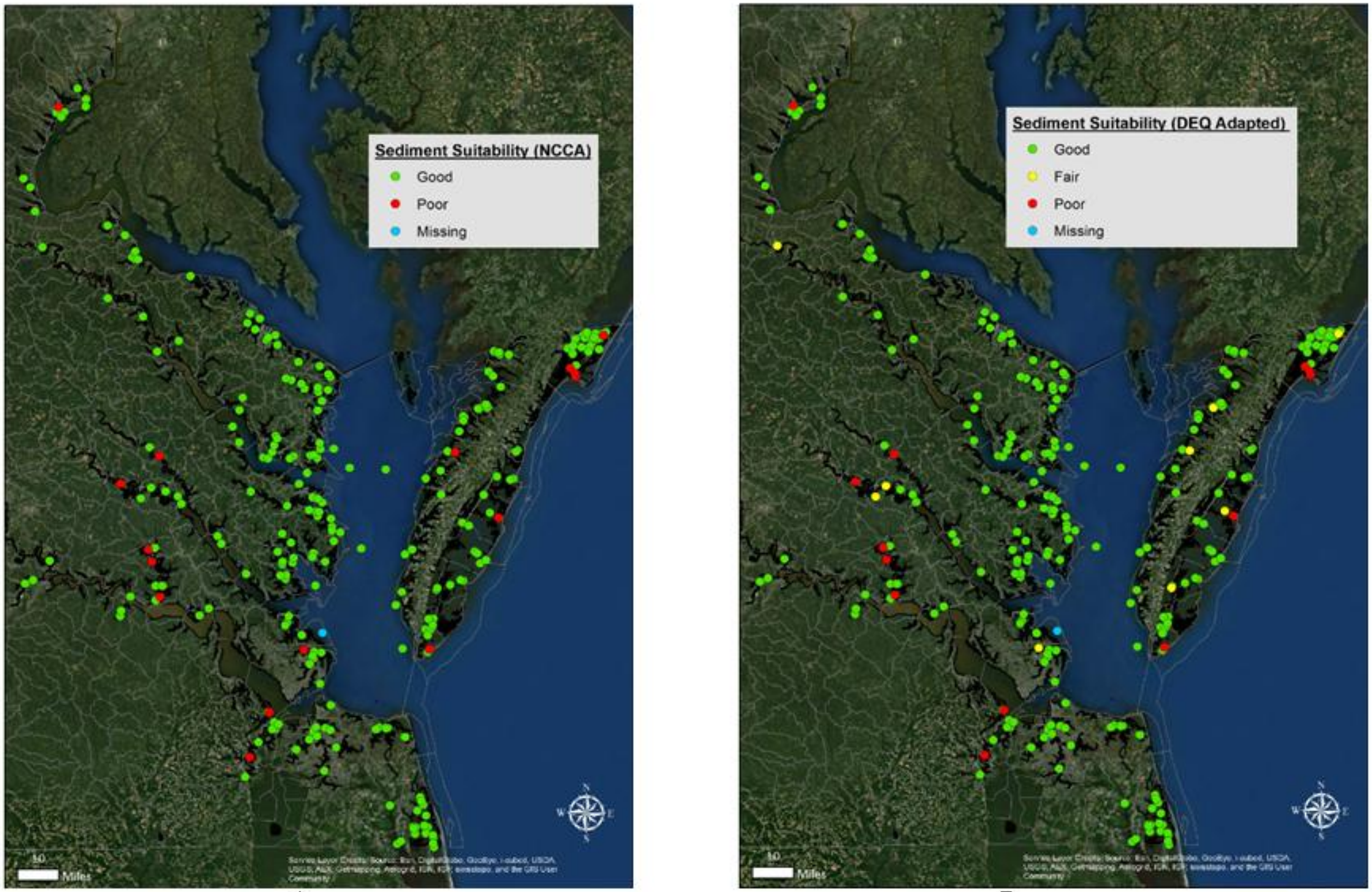
Figure 4.5-10 Characterization of Sites by Sediment Toxicity Class. The endpoint of the ten-day, static acute toxicity test was mortality of the test organism, and results were expressed as percent control-corrected survivorship (C-CS). The test organisms were the marine amphipods *Ampelisca abdita* prior to 2010 and *Leptocheirus plumulosus* thereafter.

* Survivorship was either greater than 80.00% but statistically different from control, or less than 80.00% but not statistically different from control.

Figure 4.5-11 illustrates the geographic distribution of the 273 sites with their sediment toxicity classifications following (A) the NCCA and (B) the DEQ adapted criteria. In recent years, a number of sites in the tidal freshwater and oligohaline zones of the Rappahannock, Mattaponi, Pamunkey, and Chickahominy Rivers have suffered from significant mortality as a result of apparent activity of iron reducing bacteria. A gelatinous orange-brown slime has appeared on the surface of the test sediments and the walls of test vessels, accompanied by a precipitous decline in pH (from pH ~7.0 to pH 4.0 or below). No significant chemical contamination was identified in these sediments, and the mortality has been attributed to a biological origin rather than to direct chemical contamination, but the sites have still been included in the summary statistics and the figures.

It is interesting to note that, as is often the case, we have not observed significant acute mortality in sediment from many of the sites where we have measured significant chemical contamination. This is especially notable in the Elizabeth River system, where sediment contamination by many metals (Zn, Ni, Cu, Cd, and As) and organic compounds (primarily by PAHs and PCBs) is widespread. This may be an indication that the chemical contaminants are in a form not readily available to the benthic community (or test organism), or that the available concentrations are so low that only chronic effects would be evident. In contrast, significant toxicity is often observed during tests of sediment in which chemical analyses have not revealed a probable cause of the toxicity observed. In the environment, complex mixtures of contaminants of various classes (trace metals, pesticides, PAHs, etc.), even at relatively low concentrations, often have unpredictable and at times severe effects. This characteristic of complex chemical mixtures will be considered further in the following sections.

An *a posteriori* comparison between test results from the 2007 - 2009 period (using *A. abdita*; n = 150) and the 2011 – 2012 period (using *L. plumulosus*; n = 100) revealed that the percentage of “Poor” (significant toxicity) results did increase slightly using *L. plumulosus*, but the difference was not statistically significant with these sample sizes. A portion of this difference is attributable to the suspected contamination by iron bacteria mentioned above, that was not encountered prior to 2010. The data from 2010 (n = 24) were not included in this comparison, because the sites were selected using the national design and included a number of sites in the Chesapeake Bay mainstem where, on average, the sediment is less contaminated than in many of its minor tidal tributaries and embayments.



A B

Figure 4.5-11. Sediment Suitability Based on Control-Corrected Survivorship Following Ten-day Static Acute Toxicity Tests with Burrowing Marine Amphipods. Site characterizations (A) following the NCCA criteria and (B) following the adapted DEQ criteria described in the text. Results are missing from a single site (blue symbol) because the sandy sediment was too compacted to collect material for chemical and toxicological analyses (completeness = 99.64 ± 0.71% among 275 site visits). In several cases, the yellow "Fair" sites that appear under the DEQ characterization suggest gradients in toxicity between adjacent "Good" and "Poor" sites (*e.g.*, Pamunkey River, eastern shore Chesapeake, and coastal Delmarva).

Sediment Chemical Contamination: There are no known measures of environmental chemical contamination that correspond directly to toxicity, since toxicity, as expressed in terms of survivorship following a toxicity test, is a function of the test structure and the specific organism tested. Environmental chemical contamination is much more complex than controlled toxicity tests in the laboratory.

Effects Range Low and Effects Range Median Sediment Screening Values - Traditionally, NCCA Reports have evaluated sediment contamination based on the "Effects Range Low" (ERL) and "Effects Range Median" (ERM) sediment screening values for chemical concentrations in marine and estuarine sediments, provided by Long, MacDonald, Smith, and Calder (1995). The ERL and ERM values were defined as the concentrations of individual contaminants that were associated with 10% and 50% occurrence, respectively, of adverse effects on benthic communities from the same sites in their database. Table 4.5-9 summarizes the ERL and ERM values for the nine metals and nineteen organic compounds or classes of organic compounds for which they are available. The NCCA has traditionally evaluated the sediment of individual sites based on the number of exceedances of individual ERL and ERM values as summarized in Table 4.5-10. This method of characterization does not take into consideration the potential cumulative effects (additivity or synergism[4]) of multiple contaminants below their individual ERL or ERM thresholds.

Table 4.5-9 – Effects Range Low (ERL) and Effects Range Median (ERM) Sediment Screening Values used by the NCCA Program to Evaluate Sediment Contamination: A – Metal analytes, and B – Organic analytes (adapted from U.S. EPA, 2012, after Long, et al., 1995). See the discussion in the text for more details about the use of these sediment screening values.

A

Metal Elements	ERL (mg/Kg = ppm)	ERM (mg/Kg = ppm)
Arsenic*	8.2	70.0
Cadmium*	1.2	9.6
Chromium*	81.0	370.0
Copper*	34.0	270.0
Lead*	46.7	218.0
Mercury*	0.15	0.71
Nickel	20.9	51.6
Silver*	1.0	3.7
Zinc*	150.0	410.0

* The ERM values for these chenmicals were also used for the calculation of mean ERM Quotients (Hyland, et al., 2003)

B

Organic Compounds	ERL (ug/Kg = ppb)	ERM (ug/Kg = ppb)
Acenaphthene*	16.0	500.0
Acenaphthylene*	44.0	640.0
Anthracene*	85.3	1100.0
Flourene*	19.0	540.0
2-Methylnaphthalene*	70.0	670.0
Naphthalene*	160.0	2100.0
Phenanthrene*	240.0	1500.0
Benz(a)anthracene*	261.0	1600.0
Benzo(a)pyrene*	430.0	1600.0
Chrysene*	384.0	2800.0
Dibenzo(a,h)anthracene*	63.4	260.0
Fluoranthene*	600.0	5100.0
Pyrene*	665.0	2600.0
Low molecular-weight PAH	552.0	3160.0
High molecular-weight PAH	1700.0	9600.0
Total PAHs	4020.0	44800.0
4,4'-DDE*	2.2	27.0
Total DDT*	1.6	46.1
Total PCBs*	22.7	180.0

* The ERM values for these chenmicals were also used for the calculation of mean ERM Quotients (Hyland, et al., 2003)

Table 4.5-10 NCCA Site Characterizations based upon the Simple Numbers of ERL and ERM Exceedances. (From U.S. EPA, 2012) This rating method does not take into consideration the potential cumulative effect of multiple chemical concentrations below their individual threshold ERL and/or ERM values.

Rating	Cutpoints
Good	No contaminant concentrations exceeded the ERM, and fewer than five contaminant concentrations exceeded ERLs.
Fair	No contaminant concentrations exceeded the ERM, and five or more contaminant concentrations exceeded the ERLs.
Poor	At least one contaminant concentration exceeded the ERM.

[4] Synergism or synergistic effects refers to the interaction of multiple elements in a system to produce an effect greater than the sum of their individual effects.

Regional classifications based on the NCCA site characterizations above were determined using the cutpoints summarized in Table 4.5-11, below.

Table 4.5-11 NCCA Cutpoints for Assessing Sediment Contaminants by Region. (From U.S. EPA, 2012)

Rating	Cutpoints
Good	Less than 5% of the coastal area is in poor condition.
Fair	5% to 15% of the coastal area is in poor condition.
Poor	More than 15% of the coastal area is in poor condition.

The evaluation of the sediment analytical chemical results from 274 samples, based upon the traditional NCCA characterizations, are summarized in Table 4.5-12. Two hundred forty three of 274 results (88.7 ± 3.8%) were classified as "Good," 24 (8.8 ± 3.46%) were classified as "Fair," and seven (2.6 ± 1.9%) were classified as "Poor." Based upon the NCCA regional classification cutpoints summarized in Table 4.5-11, Virginia estuarine waters would be awarded an overall characterization of "Good." The geographic distribution of individual site results is illustrated in the map of Figure 4.5-12-A.

Table 4.5-12 Characterization of the Sediment Contamination Results from 275 Site Visits 2007 – 2012 Applying Traditional NCCA Classifications. (Criteria from U.S. EPA, 2012) This classification does not consider potential cumulative (additive or synergistic) effects of multiple concentrations at or below their respective ERL or ERM thresholds.

NCCA Sediment Contamination Class	Class Criteria	Observed Class Values N (%)
Good[1]	No ERM exceedances < 5 ERL exceedances	243 (88.69 ± 3.77%)
Fair[1]	No ERM exceedances ≥ 5 ERL exceedances	24 (8.76 ± 3.36%)
Poor[1]	≥ 1 values exceed ERM	7 (2.55 ± 1.88%)
Missing[2]	---	1 (0.36 ± 0.71%)
		275 (100.00%)

[1] Percent of 274 analyzed samples

[2] Percent of 275 site visits

Among the 274 sediment samples analyzed and the 28 individual ERM screening values evaluated in each, only nine ERM exceedances were observed, six for two metals - Zinc (5) and Nickel (1) - and three for organic compounds. Most of the zinc exceedances (3) were observed in the Elizabeth River system, where sacrificial Zinc anodes (electrodes) have long been used to prevent the corrosion of naval and commercial vessels. One location near a former marina in Potomac Creek, a tributary to the Potomac River, had ERM exceedances for both Zn and Ni. Sediment PAH concentrations there were also elevated. This site was resampled for confirmation in 2013, and a special study has been initiated in 2014 to better delimit the extent and possible source(s) of the contamination. One ERM exceedance for total DDT was observed in the Northwest Branch of the Back River (Hampton City, north of Langley Air Force Base). ERM exceedances for high molecular-weight PAHs and for dibenz(a,h)anthracene (partially redundant ERMs) were observed near an abandoned boat house in Adams Creek, a minor tributary to the lower York River. A subsequent special study in Adams Creek (November 2012) confirmed that local contamination by PAHs did exist, but revealed that sediment PAH concentrations in additional samples were well below ERM and ERL levels.

The majority of the sites graded as "Fair" were so classified because of multiple metals exceeding their ERL screening values; less so for organic compounds. ERLs for metals were exceeded 332 times at 106 sites, primarily for Arsenic (85), Nickel (80), Zinc (47) and Copper (41), and less frequently for Cadmium (23), Mercury (23), and Lead (22). There were only 74 ERL exceedances observed at 16 sites for organic compounds, primarily for PAH mixtures (62 PAH ERL exceedances at nine sites), but also for the pesticides DDT (eight sites) and Dieldrin (two sites).

Mean ERM Quotients: As pointed out above, the simple enumeration of ERL and ERM exceedances does not consider the potential additive or synergistic effects of multiple contaminants that are below their respective ERL and/or ERM thresholds. Hyland, et al. (2003) evaluated the "incidence of stress in benthic communities along the U.S. Atlantic and Gulf of Mexico coasts within different ranges of sediment contamination from chemical mixtures."

Their approach consisted of first calculating an ERM quotient (ERM-Q) for each contaminant by dividing its observed concentration by its ERM sediment screening value. ERM-Q values of 1.0 or larger indicate an exceedance of the respective ERM. Certain contaminants were excluded from this analysis because the effect of the individual analyte on benthic communities was unpredictable (*e.g.*, the metal Nickel) or an ERM was considered duplicative of other ERM screening values included in the calculation (*e.g.*, ERMs for low and high molecular-weight PAHs are duplicative of the ERM for total PAHs). The analytes for which Hyland et al. (2003) utilized ERMs in their calculations are indicated by asterisks in Table 4.5-9, above. Once ERM quotients had been calculated for each of the individual contaminants their arithmetic average was calculated, and this mean ERM-Q was subsequently compared to the observed benthic effects at the site, as evaluated with an appropriate regional Benthic Index of Biological Integrity (Engle and Summers, 1999; Paul et al., 1999; Van Dolah et al., 1999). Finally, ranges of mean ERM-Qs were associated with relative risk levels (low, medium, high, very high) to benthic communities. Tables of these ERM-Q ranges and associated risk levels were established for the Virginian, Carolinian, and Louisianan Estuarine Provinces. The ranges of ERM quotients and associated benthic risk levels for the Virginian Province are summarized in Table 4.5-13, along with the numerical distribution of the observed mean ERM quotient values among the 274 sediment analyses evaluated for this report.

Table 4.5-13 Ranges of Mean ERM Quotients and Associated Benthic Risk Levels for the Virginian Estuarine Province, with a Summary of the Numerical Distribution of Observed Risk Levels within Virginia's Estuaries 2007 - 2012. (Mean ERM-Q ranges and associated risk levels after Hyland, et al., 2003)

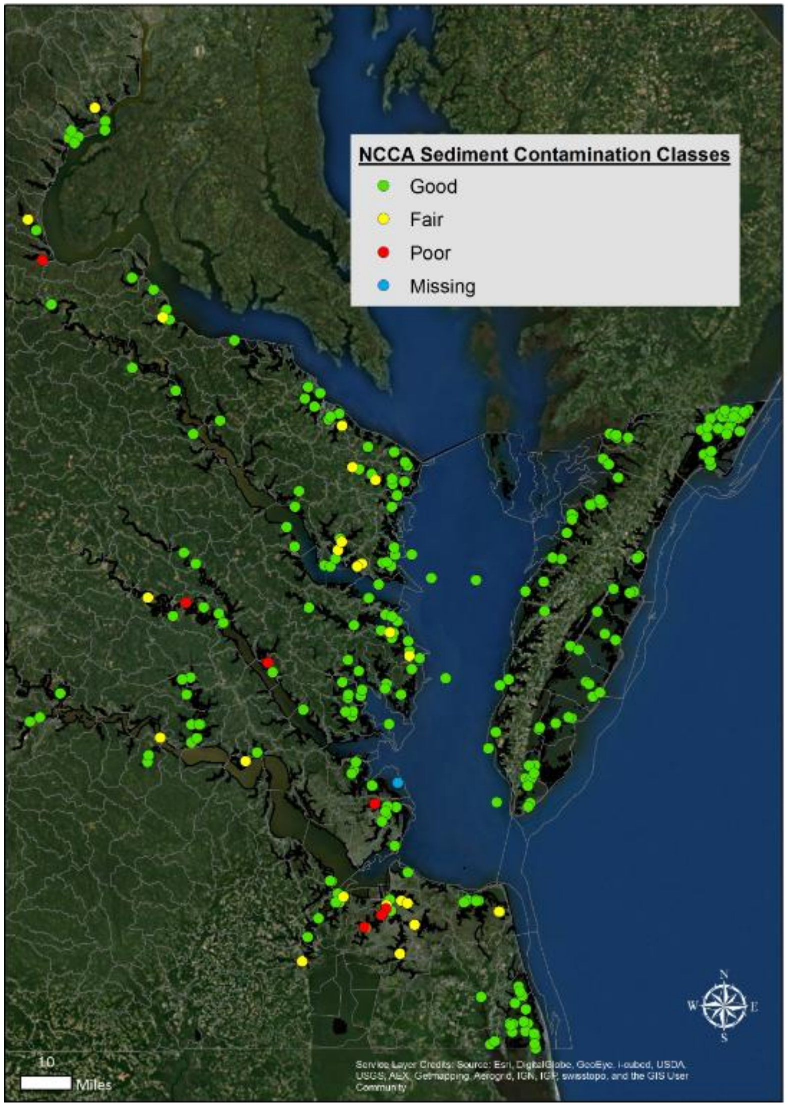
Risk of benthic impact	Mean ERM-Q Ranges	Observed Mean ERM-Q Values N (%)
Low[1]	≤ 0.022	121 (44.16 ± 5.91%)
Medium[1]	> 0.022 - 0.098	131 (47.81 ± 5.94%)
High[1]	> 0.098 - 0.473	21 (7.66 ± 3.16%)
Very High[1]	> 0.473	1 (0.36 ± 0.72%)
Missing[2]	---	1 (0.36 ± 0.71%)
[1] Percent of 274 calculated values		274 (100.00%)

[2] Percent of 275 site visits

If the relative benthic risk levels defined by Hyland et al. (2003) were to be considered equivalent to the NCCA sediment contamination classes (*i.e.*, Low Risk = "Good", Medium Risk = "Fair", and High or Very High Risk = "Poor"), then 121 results (44.2 ± 5.9%) would be characterized as "Good", 131 results (47.8 ± 5.9%) would be classified as "Fair", and 22 results (8.0 ± 3.2%) would be classified as "Poor". The regional characterization for all of Virginia's estuaries would in this case be "Fair," because the observed percentage in the "Poor" class (8.0%) was between 5.0% and 15.0% (refer to Table 4.5-11, above). The geographic distribution of these results is illustrated in the map of Figure 4.5-12-B.

The resultant higher densities of "Fair/Medium Risk" sites and "Poor/High Risk" sites is very evident when comparing Figures 4.5-12 A and B, and the geographic distribution of "High Risk" sites is quite revealing. The cluster of "High Risk" sites within the Elizabeth River system is not surprising, considering the industrial, maritime, and military history of the area. The density of "High Risk" sites in the embayments and tidal tributaries of the upper tidal Potomac River were less expected but not exceptionally surprising, considering the elevated population density, in conjunction with urbanization, industrialization, and the number and density of private and commercial boating facilities in the area. The only "Very High Risk" (mean ERMq = 0.628) site observed during the six years under consideration was near a former marina in Potomac Creek, a tributary to the Potomac River. A probabilistic site (1APOM001.96) first sampled there in 2012 exceeded the ERM screening values for Zinc and Nickel, the ERL values for eight additional metals (As, Cd, Cr, Cu, Pb, Hg, Se, and Ag) and the ERL values for DDT and 11 PAHs or PAH groups. This site was resampled in 2013, confirming the degree of pollution by metals and PAHs, and is currently (2014) the subject of a special study to determine the extent and potential sources of the contamination. The next two highest mean ERMq values were for the Adams Creek site mentioned above (8-ADA001.65 – ERLs for As and 12 PAHs plus ERMs for two other PAHs; mean ERMq = 0.292) and a site in the upper tidal Nansemond River (2CNAN017.59 – ERLs for As, Cd, Pb, Hg, Ni, Zn, DDT, and nine PAHs; mean ERMq = 0.280).

The Delmarva Peninsula, both the eastern shore Chesapeake and coastal shores, received 100% "Good" site ratings under the NCCA criteria, and at the worst individual sites with "Medium Risk" under the mean ERMq criteria (35.3%



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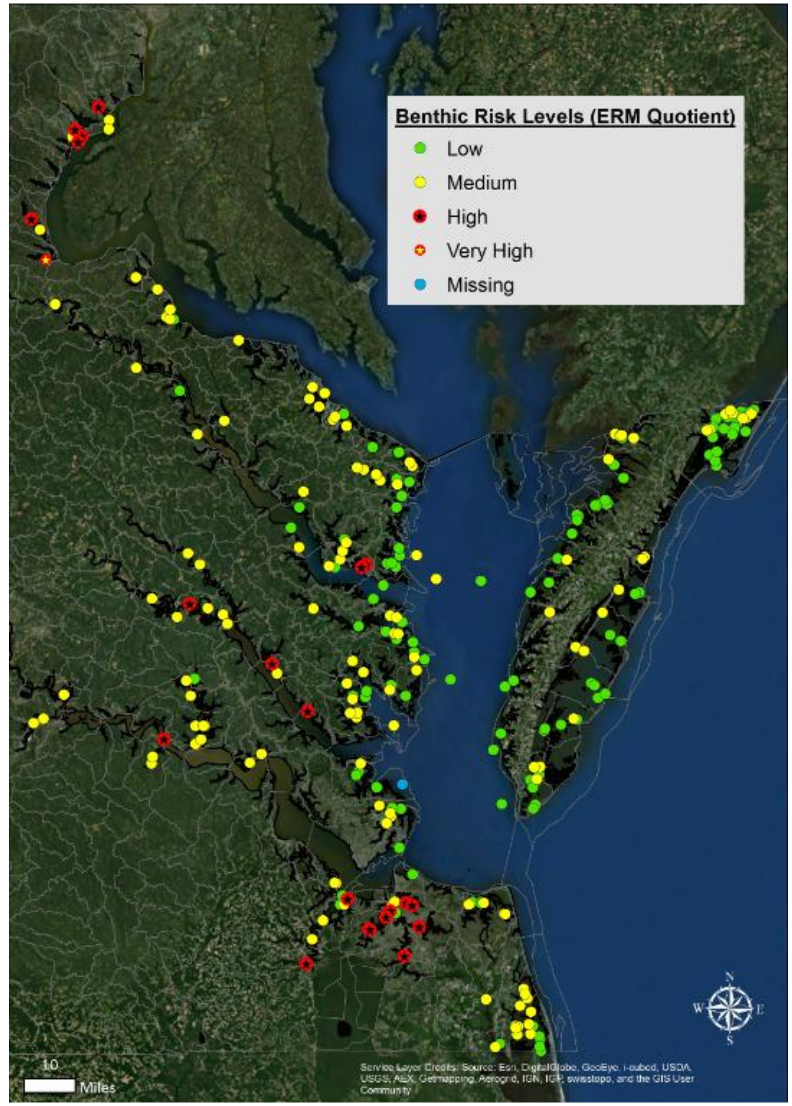


B

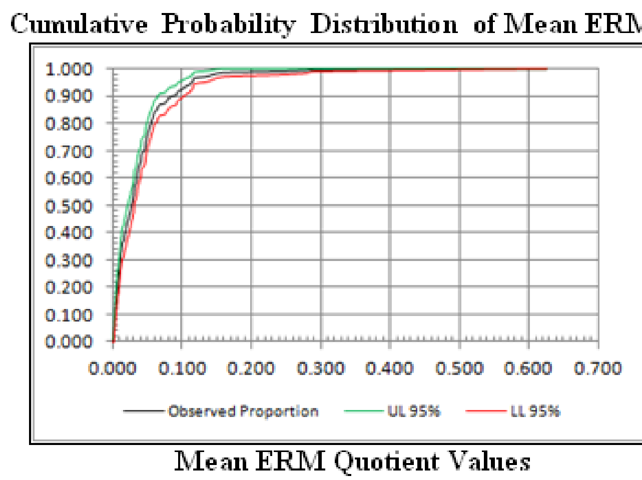
Figure 4.5-12 The Geographic Distribution and Sediment Contamination Characterization of 272 Probabilistic Estuarine Sites. Characterizations were evaluated by applying (A) traditional NCCA Criteria based on Numbers of ERL and ERM Exceedances (U.S. EPA, 2012), and (B) the Mean ERM Quotient Criteria of Hyland et al. (2003) for the Virginia Biogeographic Province. A single site (blue symbol) was not classified because its sediment was too compact to sample with the Petite Ponar grabs utilized by DEQ.

of eastern shore Chesapeake and 52.6% of coastal). Delmarva sites lose their NCCA “Good” to mean ERMq “Medium Risk” rating primarily because of ERL exceedances for As, and to a lesser extent, Ni. Arsenic is assumed to be residual, derived primarily from the poultry industry that has traditionally used the metal as a helmithicide additive to poultry feed. This practice has been greatly reduced if not eliminated in recent years.

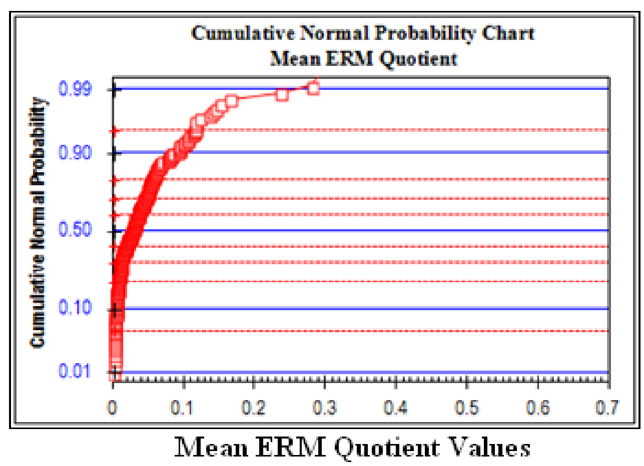
The statistical and cumulative probability distributions of Mean ERM Quotients are summarized in Figure 4.5-13-A through C, below. The apparent break points in the Cumulative Normal Probability Chart (Fig. 4.5-13-C) roughly correspond to the thresholds identified by Hyland et al. (2003) in Table 4.5-22: Low to Medium Risk – 0.02, and Medium to High Risk – approximately 0.09. The single “Very High Risk” score of 0.628 fell well above the 0.99 mark on the cumulative normal probability scale and is not plotted in Figure 4.5-13-C. It appears as though the mean ERMq scores in the Low Risk (“Good”) class have a fairly normal (natural or undisturbed?) distribution among the observed values from 0.001 to 0.022, and that the scores in the Medium Risk (“Fair”) class have a fairly normal (slightly disturbed?) distribution among the observed values between 0.023 and 0.097. It is difficult to interpret the distribution of values in the High Risk (“Poor” - mean ERMq > 0.097) class because values in the upper tail (probability above 0.90 or 90%) of the distribution are distorted by more severe contamination inputs and are also more susceptible to sampling error. It does appear, however, that the observed distribution of sediment mean ERMq scores observed in Virginia’s estuarine waters corresponds well with the distribution of scores and benthic effects observed by Hyland et al. (2003) for the Virginian Biogeographical Province.

Mean-ERMq (Hyland et al., 2003)	
N	274
Max	0.628
99th %tile	0.247
95th %tile	0.115
90th %tile	0.089
75th %tile	0.050
UL.95% Median	0.030
Median	0.028
LL.95% Median	0.026
25th %tile	0.009
10th %tile	0.004
5th %tile	0.002
1st %tile	0.002
Min	0.001
Mean	0.039
Std. Dev.	0.054
Std. Err.	0.003

A



B



C

Figure 4.5-13 – Statistical Distributions of Mean ERM Quotients among 274 Sediment Samples from Probabilistic Estuarine Sites. Cutpoints between adjacent classes in **A** come from Hyland et al (2003), summarized in Table 4.5-13. Apparent breakpoints in the Cumulative Normal Probability Chart of **C** correspond well with those observed and described by Hyland et al. (2003) for the Virginian Biogeographical Province (see text for details).

Equilibrium Partitioning Sediment Benchmark (ESB) for PAH Mixtures: The U.S. EPA has published several procedures for the derivation of contaminant equilibrium partitioning sediment benchmarks (ESBs) for the protection of benthic organisms. Such benchmarks consider the potential cumulative (additive and/or synergistic) effects of multiple related contaminants (*e.g.*, various metals or various PAHs, etc.) within the same sediment sample. The ESB calculations for PAH mixtures (U.S. EPA, 2000) were originally derived for a mixture of 34 individual compounds and subclasses of PAHs (Table 4.5-14, Carolinian and Louisianian EMAP), based upon their toxicities to benthic organisms, and their equilibrium partitioning between sediment, its total organic carbon (TOC) content, and the water in the sediment's interstitial spaces where most true, sessile benthic organisms reside (as opposed to more motile epibenthic organisms, that move about on the surface of the substrate). In calculating the ESB, the observed concentration of each individual PAH is multiplied by a toxicity coefficient and corrected for the total organic carbon content of the sediment sample. The final calculation in deriving the Total $ESB_{\mathbf{34}}$ score for a sediment sample is to sum the scores for the 34 individual analytes. Freshwater or saltwater sediments in which the Total $ESB_{\mathbf{34}}$ Score is less than or equal to 1.0 for the mixture of the 34 PAHs are acceptable for the protection of benthic organisms. If the Total ESB34 is greater than 1.0, sensitive benthic organisms may be unacceptably affected.

Only 23 of the PAHs included in the original ESB derivations were among the suite of PAH analytes included in this study (Table 4.5-14, Virginian EMAP and others), but the EPA publication cited above also provides correction factors to estimate the reliability of predicting a score for the total suite based on the results from these 23 analytes. Multiplying the total score derived from summing the 23 analytes (ESB_{23}) by a correction factor of 1.64 provides an estimate of the expected median score for the ESP_{34} among the N = 2001 reference samples initially used to derive the original ESB relationship. A Ms Excel ® spreadsheet that carries out these calculations automatically for individual site assessments based on the Sediment Quality Triad is provided in DEQ's Weight-of-Evidence workbooks. The Weight-of-Evidence assessment procedure and the associated Excel workbooks are described in DEQ's 2014 Assessment Guidance Manual (DEQ-WMA 2014).

When this correction factor was applied to the results from the 274 estuarine sediment samples in this study, estimated $ESB_{\mathbf{34}}$ scores varied from 0.000 to 120.119. One hundred ninety-seven (71.6 ± 5.4%) of the samples had expected $ESB_{\mathbf{34}}$ scores ≤ 1.000, indicating that undesirable effects from PAH contamination would not be expected to impact the benthos. Sites with estimated $ESB_{\mathbf{34}}$ scores ≤ 1.000 were consequently characterized as being of "Low" risk to benthic communities. Sites with estimated $ESB_{\mathbf{34}}$ scores greater than 1.000 and less than or equal to 2.000 (N = 21; 7.7 ± 3.2%) were characterized as being of "Medium" risk to benthic communities, because a marginal rather than a severe impact would be expected. Estimated $ESB_{\mathbf{34}}$ scores greater than 2.000 and less than or equal to 5.000 (N = 40; 14.6 ± 4.2%) were characterized as being of "High" risk to benthic communities, and sites where estimated $ESB_{\mathbf{34}}$ scores exceeded 5.000 (N = 17; 6.2 ± 2.9%) were characterized as being of "Very High" risk to benthic communities. The ranges of estimated $ESB_{\mathbf{34}}$ (adjusted ESB_{PAHs}) scores, the resultant characterizations, and the numeric distribution of the results are summarized in Table 4.5-15, below. Combining the two classes of "High Risk" and "Very High Risk" into a single characterization of "Poor" produces a total of 57 samples (20.8 ± 4.8%) in the "Poor" class. Following the regional assessment guidelines in Table 4.5-11, Virginia's estuarine waters would earn an overall characterization of "Poor" (more than 15% of the sites in "Poor" condition) for PAH contamination in the sediment.

The statistical and geographical distributions of estimated $ESB_{\mathbf{34}}$ results are summarized and illustrated in Figure 4.5-14. Geographically, the distribution of sites with high PAH contamination appears very similar to that observed for high mean ERM Quotients in Figure 4.5-12-B. This is not surprising, because the mean ERM Quotient calculations include quotients for a number of individual PAHs as well as those for metals, pesticides, and other organic compounds. Geographically, the PAHs tend to be more prevalent in industrialized and urbanized areas than in agricultural areas, as did the higher mean ERM Quotients. The vast majority of the PAHs observed were pyrogenic in origin (combustion products primarily of petroleum and petroleum derivatives – fuels, plastics, other synthetic organic compounds – but also of other vegetable derivatives such wood, coal, and even tobacco). The widespread distribution of PAHs in sediments along the western Chesapeake shore may be related to boating activity and the historical use of creosote and other pine tar derivatives for the preservation of wooden boats and the pilings and decking of wharfs. The population density and associated boating activity has historically been considerably lower on the eastern shore of the Bay, coastal Delmarva, and in Back Bay.

The ESBs for PAH mixtures, however, appear to be considerably more stringent in their environmental evaluations than the ERM Quotients, producing a noticeably higher proportion of "High" and "Very High" characterizations (20.8% as opposed to 8.0% for mean ERMq). There are several factors that contribute to this difference. The mean ERMq calculation includes eight metals, total PCBs, and DDT along with 13 PAHs. In many cases low ERM quotients for other non-PAH analytes may pull the average value downward. The $ESB_{\mathbf{PAH}}$ includes 23 PAHs in its calculations (but

Table 4.5-14 PAHs measured in various sediment monitoring programs. See Di Toro and McGrath (2000) for data sources. The 34 PAHs and PAH groups listed under the Carolinian and Louisianian EMAP studies provided the basis for calculating the original Equilibrium Partitioning Sediment Benchmark (ESP) for PAH mixtures. EPA's Procedures…[5] (2003a) explains how to estimate the value of the 34 PAH ESB based on the 23 PAHs listed under the Virginian EMAP Program.

Parameter	NOAA	SFEI	San Diego	Southern California	NY/NJ REMAP[A]	Virginian EMAP[B]	Elliott Bay	Carolinian EMAP	Louisianian EMAP
Acenaphthene	x	x	x	x	x	x	x	x	x
Acenaphthylene	x	x	x	x	x	x	x	x	x
Anthracene	x	x	x	x	x	x	x	x	x
Chrysene	x	x	x	x	x	x	x	x	x
Fluoranthene	x	x	x	x	x	x	x	x	x
Fluorene	x	x	x	x	x	x	x	x	x
naphthalene	x	x	x	x	x	x	x	x	x
Phenanthrene	x	x	x	x	x	x	x	x	x
Pyrene	x	x	x	x	x	x	x	x	x
Benzo(k)fluoranthene	x	x	x	x	x	x	x	x	x
Benzo(b)fluoranthene	x	x	x	x	x	x	x	x	x
Benzo(a)pyrene	x	x	x	x	x	x	x	x	x
Benzo(a)anthracene	x	x	x	x	x	x	x	x	x
Benzo(e)pyrene	x	x	x	x	x	x	x	x	x
Benzo(g,h,i)perylene	x	x	x	x	x	x	x	x	x
Dibenz(a,h)anthracene	x	x	x	x	x	x	x	x	x
2,6-dimethylnaphthalene	x	x	x	x	x	x	x	x	x
Indeno(1,2,3-cd)pyrene	x	x	x	x	x	x	x	x	x
1-methylnaphthalene	x	x	x	x	x	x	x	x	x
2-methylnaphthalene	x	x	x	x	x	x	x	x	x
Perylene	x	x	x	x	x	x	x	x	x
1-methylphenanthrene	x	x	x	x	x	x	x	x	x
2,3,5-trimethylnaphthalene	x	x	x	x	x	x	x	x	x
2-methylanthracene							x		
2-methylphenanthrene		x					x		
3,6-dimethylphenanthrene									
9-methylanthracene							x		
9,10-dimethylanthracene		x					x		
C1-benzo(a)anthracenes/chrysenes							x	x	x
C2-benzo(a)anthracenes/chrysenes							x	x	x
C3-benzo(a)anthracenes/chrysenes							x	x	x
C4-benzo(a)anthracenes/chrysenes								x	x
C1-fluoranthenes/pyrenes								x	x
C2-fluoranthenes/pyrenes							x		
C1-fluorenes							x	x	x
C2-fluorenes							x	x	x
C3-fluorenes							x	x	x
C1-naphthalenes							x	x	x
C2-naphthalenes							x	x	x
C3-naphthalenes							x	x	x
C4-naphthalenes							x	x	x
C1-phenanthrenes/anthracenes							x	x	x
C2-phenanthrenes/anthracenes							x	x	x
C3-phenanthrenes/anthracenes							x	x	x
C4-phenanthrenes/anthracenes								x	x
Total Number of PAHs[B]	23	25	23	23	23	23	32	34	34
Number of data points	640	137	182	40	153	318	30	280	229

[A] Benzo(b)fluoranthene and benzo(k)flouranthene were measured together.
[B] A specific C1-PAH was not included in the total if the C1 alkylated PAH series was measured. For example, 1-methylnaphthalene was not included in the total if the C1-naphthalenes were measured.

[5] Taken from U.S. EPA. 2003a. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA-600-R-02-013. Office of Research and Development. Washington, DC 20460

is corrected upward to estimate the effects of 34 PAHs), includes coefficients for the relative chemical toxicity of certain individual PAHs plus their alkylated analogs (which might not be analyzed for individually), and also applies a correction for PAH availability based on the concentration of total organic carbon in the sediment.

Table 4.5-15 Summary of Sample Results from the Calculation of Equilibrium Partitioning Sediment Benchmarks for PAH Mixtures. Estimated ESB_{34} scores were calculated on the basis of results from the analysis of 23 PAHs in each of 274 estuarine sediment samples, following procedures described by EPA (2003a). The ESB_{23} was multiplied by a correction factor of 1.64 to estimate the expected median value (ESB_{34}) expected from a similar sample evaluated for a total of 34 PAHs (see Table 4.5-14).

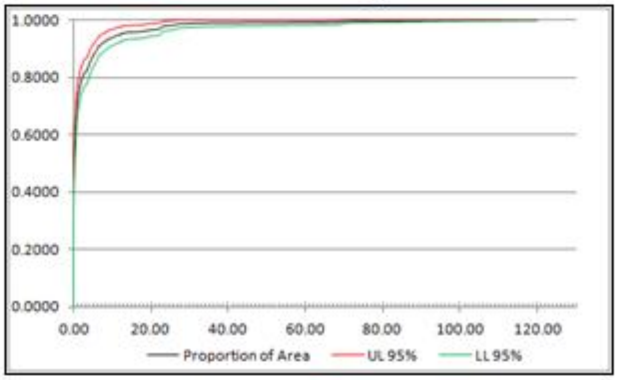
Risk of benthic impact	Adjusted ESB_{PAHs} Ranges	Observed ESB Values N (%)
Low[1]	≤ 1.000	196 (71.53 ± 5.37%)
Medium[1]	1.001 - 2.000	21 (7.66 ± 3.16%)
High[1]	> 2.000 - 5.000	40 (14.60 ± 4.20%)
Very High[1]	> 5.000	17 (6.20 ± 2.87%)
Missing[2]	---	1 (0.36 ± 0.71%)
[1] Percent of 274 calculated values		275 (100.00%)
[2] Percent of 275 site visits		

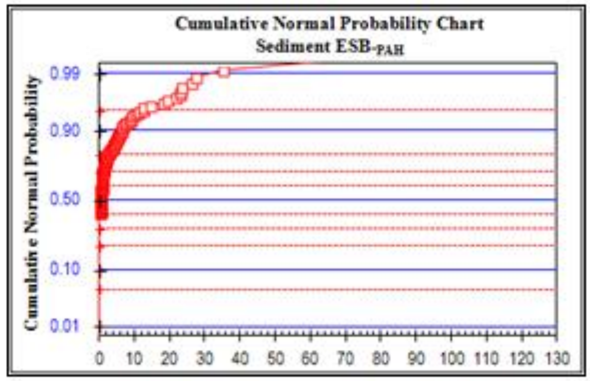
The form of the cumulative normal probability chart for ESB_{PAH} values appears to exhibit a much smoother transition from lower to medium ranges compared to the distribution for mean ERMq values. The distribution of ESB_{PAH} values appears to be truncated at the lower concentrations because the lowest 109 values (39.8%) were all tied at 0.000 – no PAHs detected in the sample. The lowest ESB_{PAH} value actually calculated from observed concentrations was 0.0002266, the 110th lowest. In the case of the mean ERMq, however, the lowest observed value was 0.00065. There was always at least one analyte with an ERM value detected in the sediment sample; the mean consequently had to be greater than zero and there was a smooth transition between near zero values and moderate values (≤ 0.022) in the “Good” class based on ERM Quotients.

Sediment Total Organic Carbon (TOC): The NCCA Program has traditionally included total organic carbon (TOC) as one element for the evaluation of sediment quality. TOC, as both a component of and a degradation product of vegetal and animal detritus, is a natural constituent of freshwater and estuarine sediments and often provides food for certain groups of benthic organisms. Excessive concentrations of TOC in local sediment deposits, however, may alter the composition of benthic communities, and promote the dominance of pollution-tolerant species. In contrast, the TOC present in the sediment may chemically bind both organic and inorganic pollutants and reduce their availability to benthic organisms, although changes in temperature and water chemistry (*e.g.*, pH and dissolved oxygen) may result in the release of previously bound contaminants. High concentrations of TOC may also indicate local foci of sediment deposition where available pollutants may accumulate. Because of the difficulty in interpreting these potentially contradictory effects of TOC in the sediment, its removal as a component indicator of sediment quality was suggested prior to the fifth NCCA Report. It would have been used alternatively in conjunction with percent fine particles (silt/clay) in the sediment to interpret other sediment quality results. After a final evaluation, TOC has been retained in its previous role as an indicator of sediment quality for NCCA Report V, and is included here for the same function.

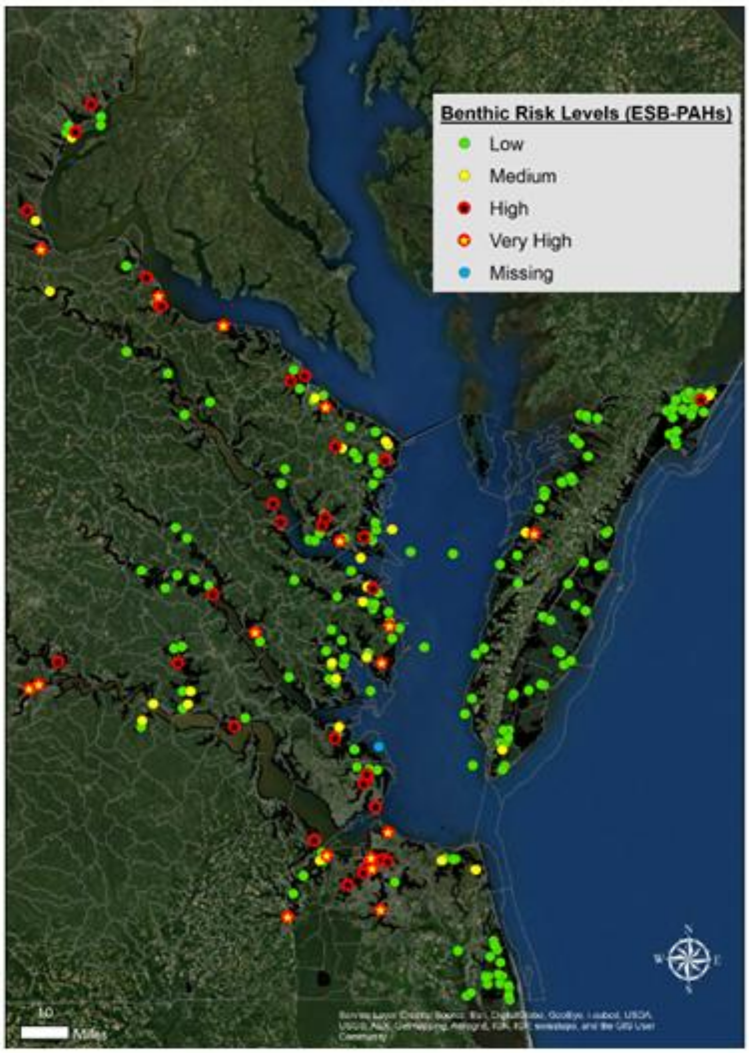
The TOC ranges utilized for characterizations here come directly from NCCA Report IV (U.S. EPA, 2012). Under this classification, 184 sites (67.1 ± 5.6%) were characterized as “Good” (TOC < 2.0%), 80 sites (29.2 ± 5.4%) were characterized as “Fair” (TOC 2.0% – 5.0%), and only 10 sites (3.7 ± 2.2%) were characterized as “Poor” (TOC > 5.0%) for sediment TOC composition. A single site lacked a sediment TOC sample because the substrate was too compacted to sample successfully. Following the guidelines provided in NCCA Report IV, Virginia’s estuarine waters would earn a “Good” overall rating based on sediment TOC, because the percentage of estuarine sites with a “Poor” characterization is well below 20%.

Cumulative Distribution of ESB_{34} for PAH Mixtures





Equilibrium Partitioning Sediment Benchmark for PAH Mixtures **Equilibrium Partitioning Sediment Benchmark for PAH Mixtures**



Sediment ESB_{PAHs}	
N	274
Max	120.119
99th %tile	43.322
95th %tile	12.342
90th %tile	6.252
80.15th %tile	2.000
75th %tile	1.400
72.35th %tile	1.000
UL 95% Median	0.221
Median	0.088
LL 95% Median	-0.044
25th %tile	0.000
10th %tile	0.000
5th %tile	0.000
1st %tile	0.000
Min	0.000
Average	2.918
Std. Dev.	10.338
Std. Err.	0.623

Figure 4.5-14 Geographic and Statistical Distributions and Site Characterizations Based on the Equilibrium Partitioning Sediment Benchmark (ESB) Scores for PAH Mixtures in 274 Sediment Samples from Probabilistic Estuarine Sites 2007 – 2012. (U.S. EPA, 2003a) The maximum calculated ESB_{34} value of 120.119 represents less than the upper 1% of the distribution, and is not plotted in the Cumulative Normal Probability Chart above.

The geographical and statistical distributions of sites based on their sediment TOC characterizations are summarized in Figure 4.5-15. The sites with the highest sediment TOC concentrations were found in low gradient, coastal plain streams such as the North Landing River (17.7% TOC), the Chickahominy River (12.9% TOC), Upper Chippokes Creek (9.5% TOC), and the Piankatank River (8.8% TOC), while those with the lowest TOC concentrations (< 0.02% TOC) were generally from channels and inlets of coastal Delmarva.

The shape of the cumulative normal probability distribution suggests that, except where scouring maintains a very low concentration of TOC in the sediment, TOC concentrations follow a smooth, naturally-regulated gradient up to the 5.0% threshold between “Fair” and “Poor” classes. The TOC concentrations at sites within the “Poor” class (TOC > 5.0%) are scattered irregularly and don’t appear to follow a set pattern. This may result from the fact that they fall at the upper extreme of the distribution, where the sampling error is higher for rare events.

Sediment Quality Index (SQI): Once all three sediment quality indicators (sediment toxicity, sediment chemistry, and sediment TOC) are scored for a site, NCCA Reports have calculated an integrated Sediment Quality Index (SQI) to characterize overall sediment quality at the site. Guidelines for determining the SQI are described in Table 4.5-16, below. In the SQI determinations that follow, the mean ERM Quotient was used to characterize sediment contamination. It was considerably more protective than the NCCA characterization based only on numbers of ERM and ERL exceedances, and less sensitive than the ESB for PAH mixtures (but more inclusive, since it includes consideration of metals, PCBs and chlorinated pesticides.

Table 4.5-16 Scoring Guidelines for Characterizing Individual Sites based on the Sediment Quality Index (SQI). (Taken from U.S. EPA, 2012)

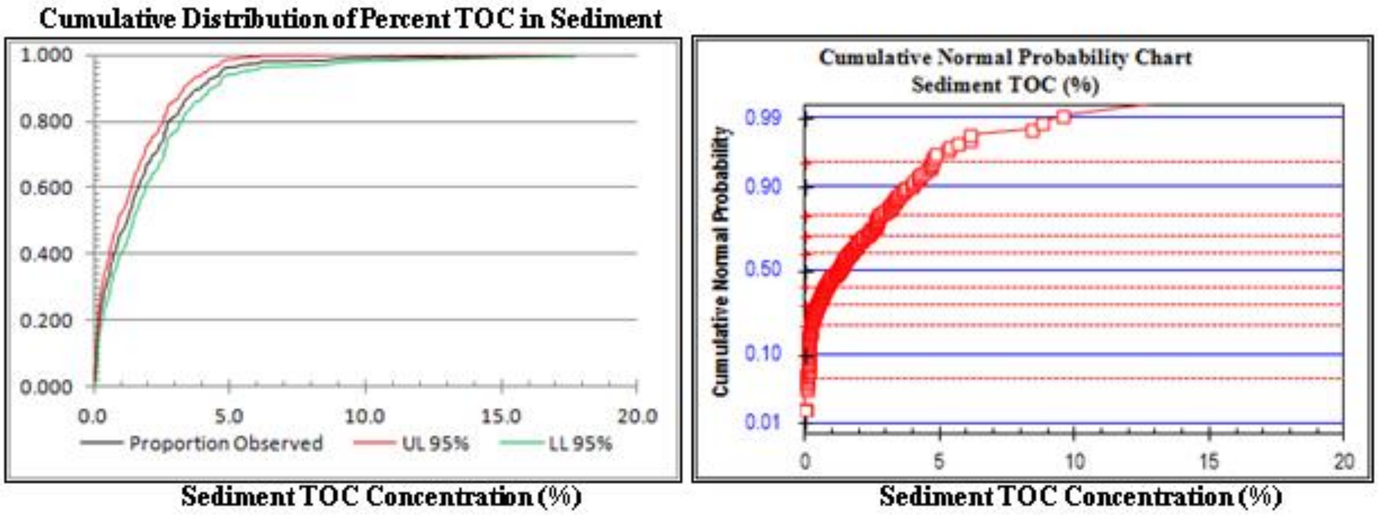
Rating	Cutpoints
Good	None of the individual component indicators is rated poor, and the sediment contaminants indicator is rated good.
Fair	None of the component indicators is rated poor, and the sediment contaminants indicator is rated fair.
Poor	One or more of the component indicators is rated poor.

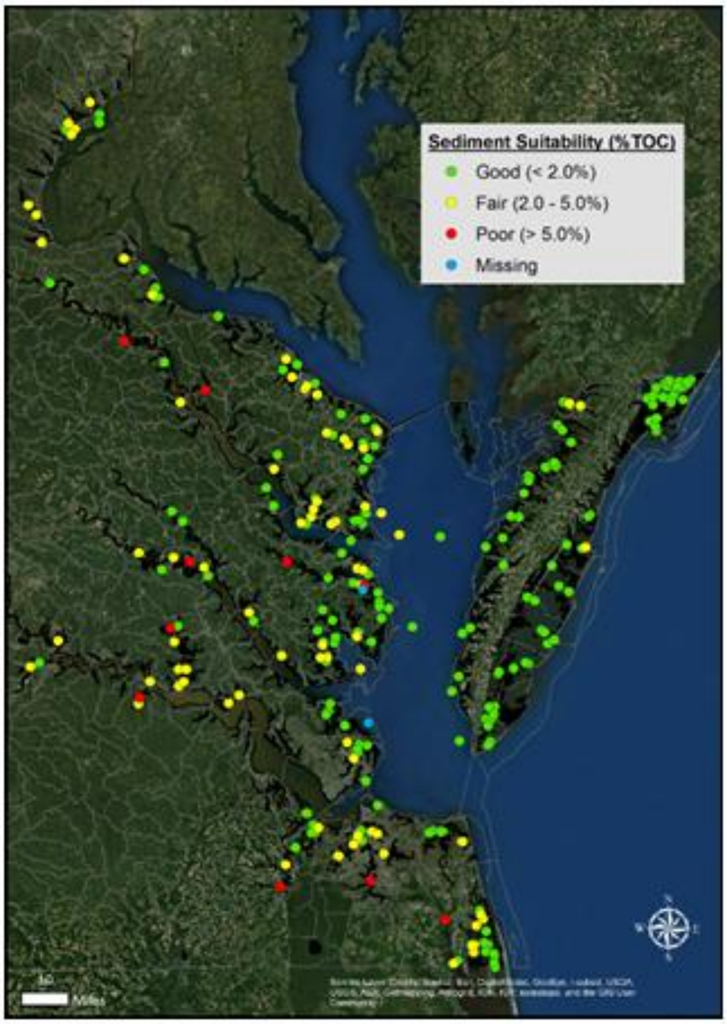
The numerical distribution of SQI scores is summarized in Table 4.5-17. Among the 274 sediment samples evaluated 116 samples (42.3 ± 5.9%) were characterized as “Good,” 120 (43.8 ± 5.9%) were characterized as “Fair,” and 38 (13.9 ± 4.1%) were characterized as “Poor”. Among the 38 characterized as “Poor”, seven were so classified solely on the basis of high TOC concentrations. It is doubtful whether a SQI should be classified as “Poor” solely on the basis of TOC, if no chemical contamination or sediment toxicity was observed in the same sample. Sites in slow moving channels or embayments surrounded by marshes would commonly have naturally elevated TOC concentrations in their sediment without necessarily having any other deleterious characteristics. A single site lacked a SQI value because the sediment there was too compacted to be sampled representatively with a Petite Ponar grab. The geographical distribution and characterizations of the sites are illustrated in the map of Figure 4.5-16. No statistical distributions are included in the figure because the SQI is measured on a discontinuous, unquantifiable ordinal scale.

Table 4.5-17 - Site Suitability as a function of the Sediment Quality Index (SQI). The single missing value was from a site where the sediment was too compacted to sample with a Petite Ponar grab. (Defined ranges and thresholds are from NCCA Report IV – U.S. EPA. 2012).

Sediment Quality Index (SQI)	Cutpoint Criteria	Observed SQI Values N (%)
Good[1]	No Component "Poor" Sediment Contamination "Good"	116 (42.34 ± 5.88%)
Fair[1]	No Component "Poor" Sediment Contamination "Fair"	120 (43.80 ± 5.90%)
Poor[1]	One or more Components "Poor"	38 (13.87 ± 4.11%)
Missing[2]	---	1 (0.36 ± 0.71%)
		275 (100.00%)

[1] % of 274 determined SQIs
[2] % of 275 site visits





Sediment TOC (%)	
N	274
Max	17.700
99th %tile	8.985
95th %tile	4.641
90th %tile	3.857
75th %tile	2.559
UL 95% Median	1.338
Median	1.210
LL 95% Median	1.082
25th %tile	0.289
10th %tile	0.087
5th %tile	0.058
1st %tile	0.000
Min	0.000
Mean	1.694
Std. Dev.	1.993
Std. Err.	0.120

Figure 4.5-15 Geographical and Statistical Distributions of Sites Based on Total Organic Carbon Concentrations (%) in Sediment. High TOC concentrations (> 5.0%) are generally associated with areas of sediment deposition, often in low gradient, slowly flowing tidal waters or in marshes, while sites with very low TOC concentrations (< 2.0% - sandy substrates) are often associated with strong currents or dynamic wave action – areas of sediment scouring.

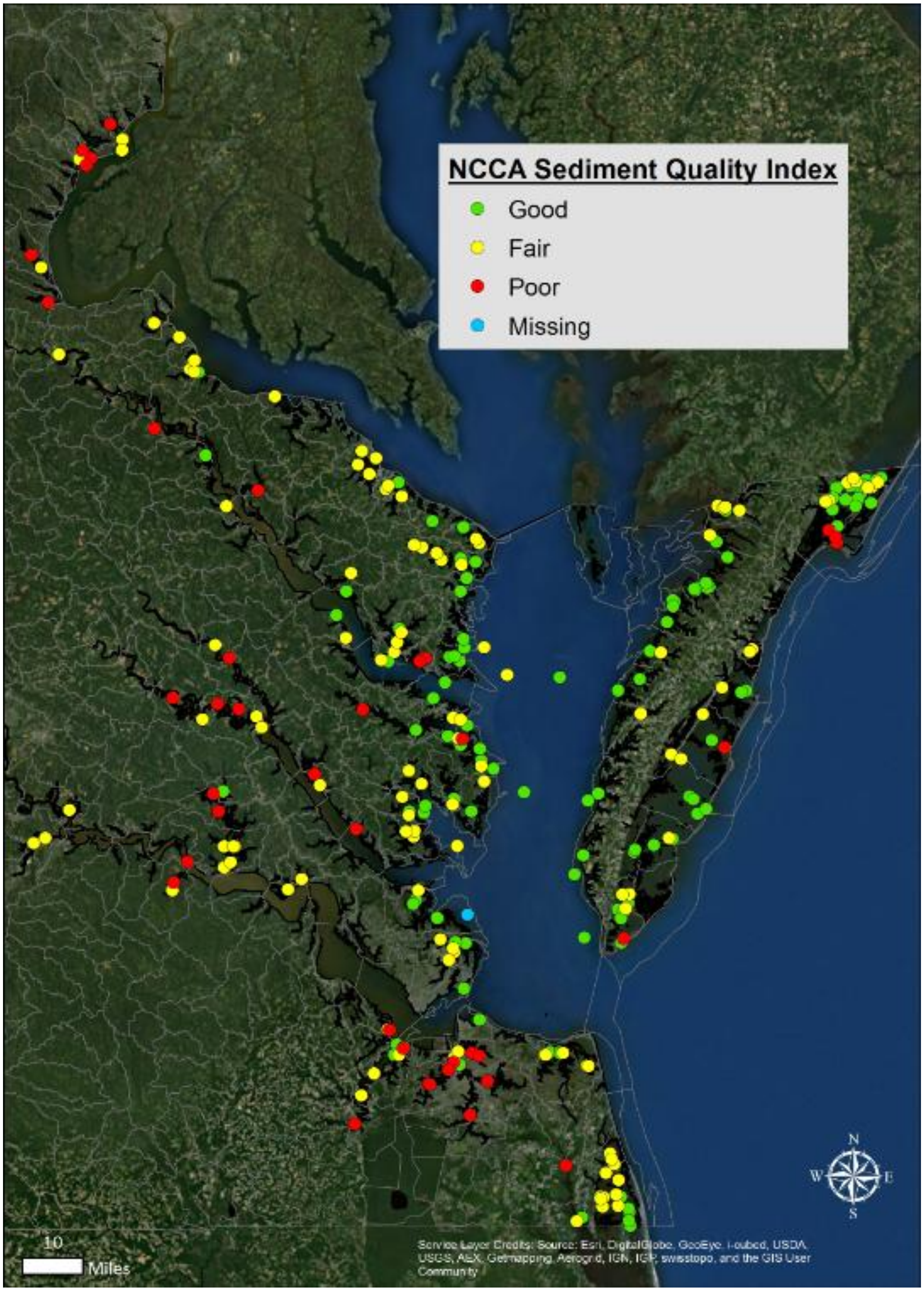


Figure 4.5-16 Geographical Distribution and Characterization of 273 Estuarine Probabilistic Sites based on the Sediment Quality Index (SQI). Seven sites were characterized as “Poor” solely on the basis of high TOC concentrations without corroborative chemical contamination or sediment toxicity. One site was not evaluated because its sediment was too compacted to be sampled representatively. No statistical or cumulative probability distributions are provided because the variable (SQI) is evaluated on a discontinuous, unquantifiable Ordinal Scale.

Based on the NCCA guidelines in Table 4.5-18, below, Virginia's region-wide estuarine sediments would be characterized as "Fair," since the percentage of sites with "Poor" sediment was more than 5% and less than 15% and the percentage "Good" was less than 50%. This characterization would not change, even if the seven sites characterized as "Poor" on the basis of TOC alone were scored otherwise.

Table 4.5-18 Scoring Guidelines for Characterizing Regions based on the Sediment Quality Index (SQI). (Taken from U.S. EPA, 2012)

Rating	Cutpoints
Good	Less than 5% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.
Fair	5% to 15% of the coastal area is in poor condition, or 50% or less of the coastal area is in good condition.
Poor	More than 15% of the coastal area is in poor condition.

Benthic Quality Index: A benthic index, also commonly referred to as a Benthic Index of Biological Integrity or B-IBI, is a scientific tool used to identify, classify, and interpret the structure and function of benthic communities, often in relation to environmental stressors such as water pollution. Such indices are generally derived from the results of local or regional benthic surveys, and are consequently geographically restricted in their application. There are three commonly applied regional benthic indices that are appropriate for use in Virginia's estuarine waters, the Chesapeake Bay Program B-IBI (CBP B-IBI - Weisberg et al., 1997), the Mid-Atlantic B-IBI (MAIA B-IBI - Llansó et al., 2002a, 2002b) and the EMAP Index of Estuarine Condition for the Virginian Biogeographic Province (EMAP IEC – Paul et al., 2001). The CBP B-IBI was developed specifically for estuarine waters of the Chesapeake Bay watershed and it is the most appropriate for use in those waters. The MAIA B-IBI was developed for waters of the Mid-Atlantic Region, which includes the estuarine waters of the Delaware Bay and Chesapeake Bay watersheds, the coastal bays of the Delmarva Peninsula, and the Albemarle-Pamlico estuarine system of southeastern Virginia and northeastern North Carolina. It is the only one of the three indices that is appropriate in all of Virginia's estuarine waters. The EMAP IEC was developed for the Virginian Biogeographic Province, which extends from Cape Cod to the mouth of Chesapeake Bay, but excludes the southeastern Virginia coastal area. All three indices were calculated for the benthic data from each site in this study, but most weight was given to the interpretation of CBP B-IBI within the Chesapeake watershed, and to the interpretation of the MAIA B-IBI in coastal waters of Delmarva and the Back Bay/North Landing River portion of the Pamlico Sound system.

The CBP B-IBI and the MAIA B-IBI are both multimetric indices based on the same scoring system, wherein each component (metric) of the index receives a score of 1, 3, or 5 depending upon whether it indicates, respectively, a degraded, intermediate/marginal, or non-degraded benthic community. A final score for each benthic sample is calculated as the arithmetic mean of the individual metric scores. Although the selection and the number of metrics may vary with the B-IBI used and among various habitat types, the final score is always a value between 1.00 and 5.00. In practice, the final scores are usually expressed to one decimal place.

The CBP B-IBI is scored as summarized in Table 4.5-19, following guidelines defined in Weisberg et al. (1997) and in various CBP guidance documents. The published scoring system for the MAIA B-IBI (Llansó et al., 2002a, 2002b), although calculated on the same basis, only differentiates between stressed (score < 3.0) and unstressed benthic communities (score ≥ 3.0). For the purpose of the current report, we have taken the liberty of applying the finer gradations of the CBP B-IBI to both indices in order to integrate the two scoring systems and to provide geographic continuity. Since both scoring systems use the same threshold to identify benthic communities that "Meet Goals," or are "Unstressed" (*i.e.*, are in "Good" condition, and the number of scores in the "Marginal" or "Fair" range is relatively low (< 10.0%), and 70% or more of the samples are from the Chesapeake Bay watershed and are appropriately characterized using the CB B-IBI, this integration of scoring systems should have a minimal effect on the comprehensive, overall characterization of Virginia's estuarine waters.

Table 4.5-19 Benthic Community Condition as evaluated by the Chesapeake Bay Program's Benthic Index of Biotic Integrity (CBP B-IBI). Scores within the Chesapeake Bay watershed were based on the CBP B-IBI (Weisberg et al., 1997); scores elsewhere were based on the MAIA B-IBI (Llansó et al., 2002a, 2002b). Defined ranges and thresholds are from Weisberg et al. (Ibid).

B-IBI Classes	B-IBI Score Ranges	Observed B-IBI Values N (%)
Meets Goals	≥ 3.00	126 (45.82 ± 5.91%)
Marginal	2.65 - 2.99	26 (9.45 ± 3.47%)
Degraded	2.01 - 2.64	51 (18.55 ± 4.61%)
Severely Degraded	≤ 2.00	72 (26.18 ± 5.22%)
		275 (100.00%)

Applying the integrated scoring system described above, 45.8 ± 5.9% of Virginia's estuarine sites scored "Meets Goals" or "Good" for benthic community well-being, and 9.5 ± 3.5% scored as "Marginal" or "Fair." A total of 123 sites (44.7 ± 5.9%) scored as "Degraded" or "Severely Degraded." The geographical and statistical distributions of sites based on their B-IBI scores are presented in Figure 4.5-17. The fact that B-IBI scores are discontinuous and have a finite number of possible values is evident in the two cumulative distributions. Numerous tied values gave rise to the stepwise shape of the cumulative probability distribution. The total of 275 calculated benthic scores resulted in fewer than 30 distinct values. Consequently the number of individual points plotted in each cumulative probability distribution is greatly reduced; most points represent a varying number of tied individual scores. Nevertheless, the straight line form of the cumulative normal probability chart suggests that the variation in the integrated B-IBI scores is essentially symmetrical and approximately normally distributed.

The NCCA guidelines in Report IV (U.S. EPA, 2012) for regional characterizations based on benthic scores indicates that regions with more than 20% of the sites in "Poor" condition (i.e., "Degraded" or "Severely Degraded") should be characterized as "Poor" (See Table 4.5-20, below). Based on the integrated scores calculated with the CBP B-IBI and the MAIA B-IBI, Virginia's estuaries rate an overall characterization of "Poor" for benthic community condition.

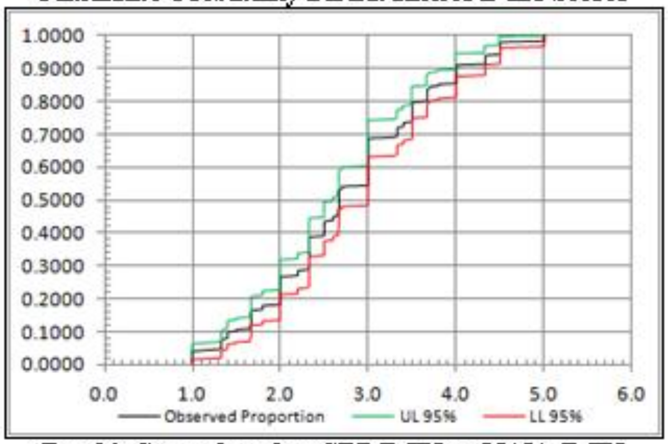
Table 4.5-20 NCCA Guidelines for Regional Characterization based on Benthic Indices (from U.S. EPA, 2012).

Regions	Less than 10% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.	10% to 20% of the coastal area is in poor condition, or 50% or less of the coastal area is good condition.	More than 20% of the coastal area is in poor condition.

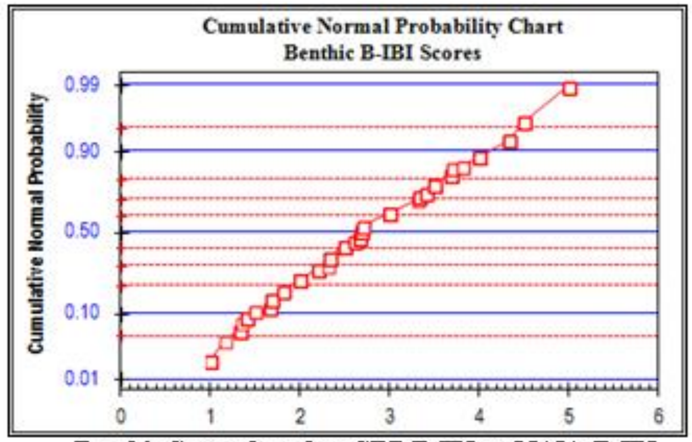
Often the causes of stress and/or degradation of benthic communities are not readily apparent. In many cases where chemical contamination at a site was well documented, no significant sediment toxicity was observed, and the benthic community appeared to be healthy. Often, degraded benthic communities may exist where neither chemical contamination nor sediment toxicity was evident. The general distribution of sites with degraded benthos within Chesapeake Bay, especially along the western shore and in the Elizabeth River system, corresponds geographically with the distributions of chemical contaminants characterized by mean ERM Quotients (Figure 4.5-12-B) and Equilibrium Partitioning Sediment Benchmarks for PAH mixtures (Figure 4.5-14), and to a lesser extent with the geographic distribution of observed sediment toxicity (Figure 4.5-11). When comparisons are made site by site, however, it is rare to observe a case where the condition of the benthic community, the observed sediment toxicity, and confirmed sediment contamination are all in agreement. This situation will be discussed in more detail in the section on weight-of-evidence assessments later in this report.

There are many other potential causes of benthic degradation. Excessive sedimentation can smother much of the benthos. Prolonged low near-bottom dissolved oxygen concentrations may devastate local benthic communities. Such DO depression commonly results from nutrient enrichment and eutrophication, but may also result from seasonal stratification and reduced mixing of waters in deep channels during the summer months. In areas exposed to dynamic wave action, or in channels scoured by strong currents, substrates are usually very sandy, unstable, and relatively devoid of benthic organisms. Such cases are generally evident from the observation of local conditions in the field and from sediment particle size analyses (predominantly coarse sand with few fine silt or clay particles) and TOC content (very low). Many of the sites that have degraded benthos along coastal Delmarva occur in tidal channels that fall into this category. Another potential cause of degraded benthos is predation. Cownose rays (*Rhinoptera bonasus*), which are common in the shallow waters of Chesapeake Bay in the summer, commonly feed

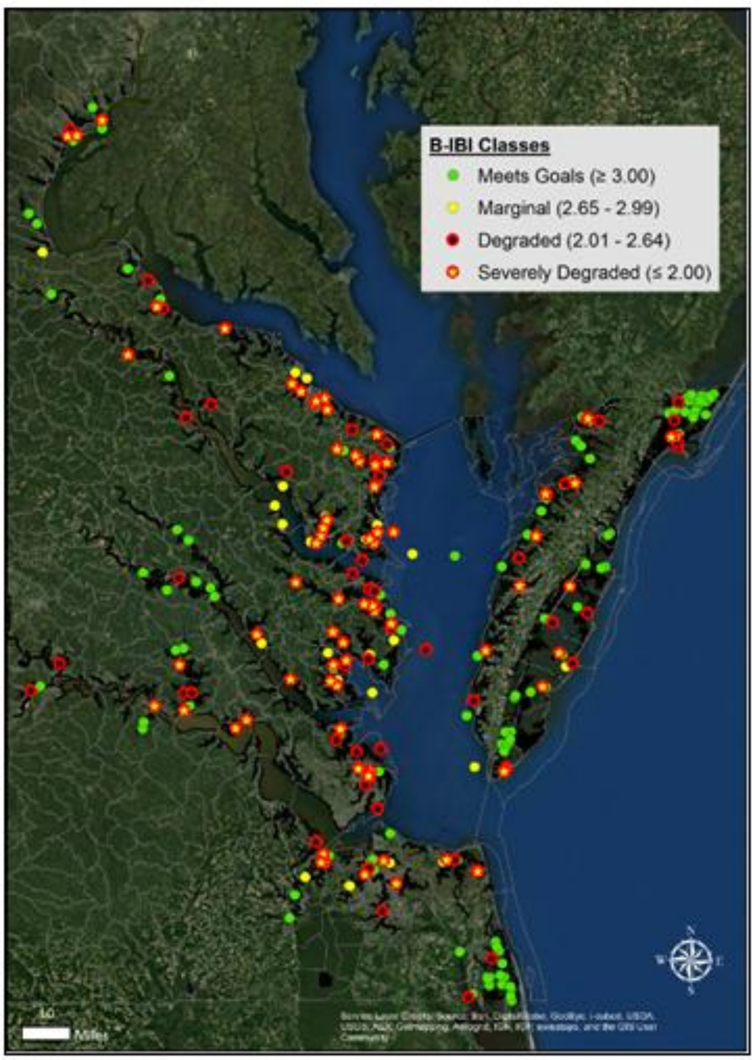
Cumulative Probability Distribution of B-IBI Scores



Benthic Scores based on CBP B-IBI or MAIA B-IBI



Benthic Scores based on CBP B-IBI or MAIA B-IBI



Benthic IBI Scores	
N	275
Max	5.00
99th %tile	5.00
95th %tile	4.50
90th %tile	4.00
75th %tile	3.50
UL 95% Median	2.81
Median	2.67
LL 95% Median	2.53
25th %tile	2.00
10th %tile	1.50
5th %tile	1.33
1st %tile	1.00
Min	1.00
Average	2.77
Std. Dev.	0.96
Std. Err.	0.06

Figure 4.5-17 Geographical and Statistical Distributions of 273 Estuarine Probabilistic Sites based on their Benthic IBI Scores. Return visits and re-sampling at two sites produced essentially identical B-IBI scores. Sites within the Chesapeake Bay watershed were scored with the CBP B-IBI; sites elsewhere were scored with the MAIA B-IBI. (See text for details.)

in schools and can devastate a local benthic community by stirring up the substrate with their fins and sucking up oysters, clams and other invertebrates that they crush with their dental plates. In short, a single visit, one-time snapshot of conditions at a site may be insufficient to identify the causes of benthic degradation, unless the causes are strongly indicated by at least two of the temporally integrative elements of the sediment quality triad (*i.e.*, sediment chemistry, sediment toxicity, and benthic community wellbeing).

Integrated Site Score: In its most recent report (U.S. EPA, 2012) the NCCA utilized five separate indices (Water Quality Index, Sediment Quality Index, Benthic Index, Coastal Habitat Index, and Fish Tissue Contaminants Index) to provide an integrated overall condition for each region in the report. Each of the available indexes was scored numerically as follows: good = 5; good to fair = 4; fair = 3; fair to poor = 2; and poor = 1. The integrated score was then calculated as the simple (unweighted) arithmetic mean of the available index scores. The final regional rating scores were also based on a 5-point system, where a score of less than 2.0 was rated poor; 2.0 to less than 2.4 was rated fair to poor; 2.4 to less than 3.7 was rated fair; 3.7 to 4.0 was rated good to fair; and greater than 4.0 was rated good.

Coastal habitat and fish tissue indices are not included in Virginia's state design estuarine probabilistic program, although these data are collected nationally on a five-year rotating schedule in conjunction with the National Aquatic Resource (Coastal) Surveys. Individual estuarine sites in Virginia were consequently characterized with an Integrated Site Score (ISS) based on the first three indices (WQI with clarity, SQI, and B-IBI) on a scale similar to that used by the NCCA. Most individual site characteristics and integrated indexes were only rated in three categories, "Good" = 5, "Fair" = 3, and "Poor" = 1, and only one index, the B-IBI characterizations, included a "Very Poor" = 0 class. "Very Poor" and zero scores were applied only in those cases where the B-IBI indicated a "Severely Degraded" benthic community. Virginia's ISS was consequently calculated as the unweighted arithmetic mean of three site indexes and was rated as follows: ISS < 2.5 = "Poor", ISS from 2.5 to 3.5 = "Fair", and ISS > 3.5 = "Good."

Based on the scoring system described above, 115 sites (42.1 ± 5.9%) were characterized as "Good," 80 sites (29.3 ± 5.4%) were characterized as "Fair," and 78 sites (28.6 ± 5.4%) were characterized as "Poor." The overall average of the 273 site scores was 3.10, giving Virginia's estuarine waters a regional characterization of "Fair."

The great majority of sites that were rated as "Poor" by the ISS had low scores because of benthic characterizations of "Degraded" or "Severely degraded", or characterizations of "Poor" for the SQI, almost exclusively because of chemical contamination. "Poor" SQI scores (because of high chemical contamination), however, were not always associated with low benthic scores. Another individual characteristic of influence, that often depressed the WQI characterizations and consequently the ISS value, was water clarity. Adding the water clarity characterization to the other four elements (Chl-a, DIN, DIP, and $DO_{\textbf{-Bot}}$) of the WQI raised the percentage of sites in the "Poor" class from 1.5% to 17.5% (see Table 4.5-6 and Figure 4.5-7, A & B), and decreased the average WQI score from 3.84 to 2.97.

Weight-of-Evidence (WOE) Assessment: Weight-of-Evidence assessments for Aquatic Life Use (ALU) were carried out on each individual site based primarily upon the Sediment Quality Triad (SQT) of sediment chemistry, sediment toxicity, and Benthic Index of Biotic Integrity (B-IBI). All three of these measures are considered to be temporally integrative, providing an assessment of environmental conditions experienced by the benthic community prior to the time of sampling. The other water quality parameters (*e.g.*, nutrients, bacteria, dissolved metals, DO, temperature, pH, *etc*.) that are measured at probabilistic sites are considered to be isolated instantaneous observations and are insufficient for assessment purposes because the intensity and duration of such stressors are unknown. The evaluation and interpretation of the SQT is carried out with the use of an analytical matrix (Chapman et al., 1986, 1987) that is described in DEQ's Water Quality Assessment Guidance Manual for the 2014 305(b)/303(d) Integrated Water Quality Report (DEQ-WQA, 2014).

The criteria used in this WOE assessment and the Microsoft Excel® workbooks used for the process are also described in the Water Quality Assessment Guidance Manual (*Ibid*.). The site characterizations that are integrated into the WOE assessments have been discussed individually earlier in this report. They include counts of ERM and ERL exceedances (criteria from previous NCCA Reports), the Mean ERM Quotient, the Equilibrium Partitioning Sediment Benchmark for PAH mixtures (ESB_{PAHs} or ESB_{34}), the results of sediment toxicity tests, and taxonomic richness, diversity, and evenness along with the evaluation of benthic community health and function (B-IBIs).

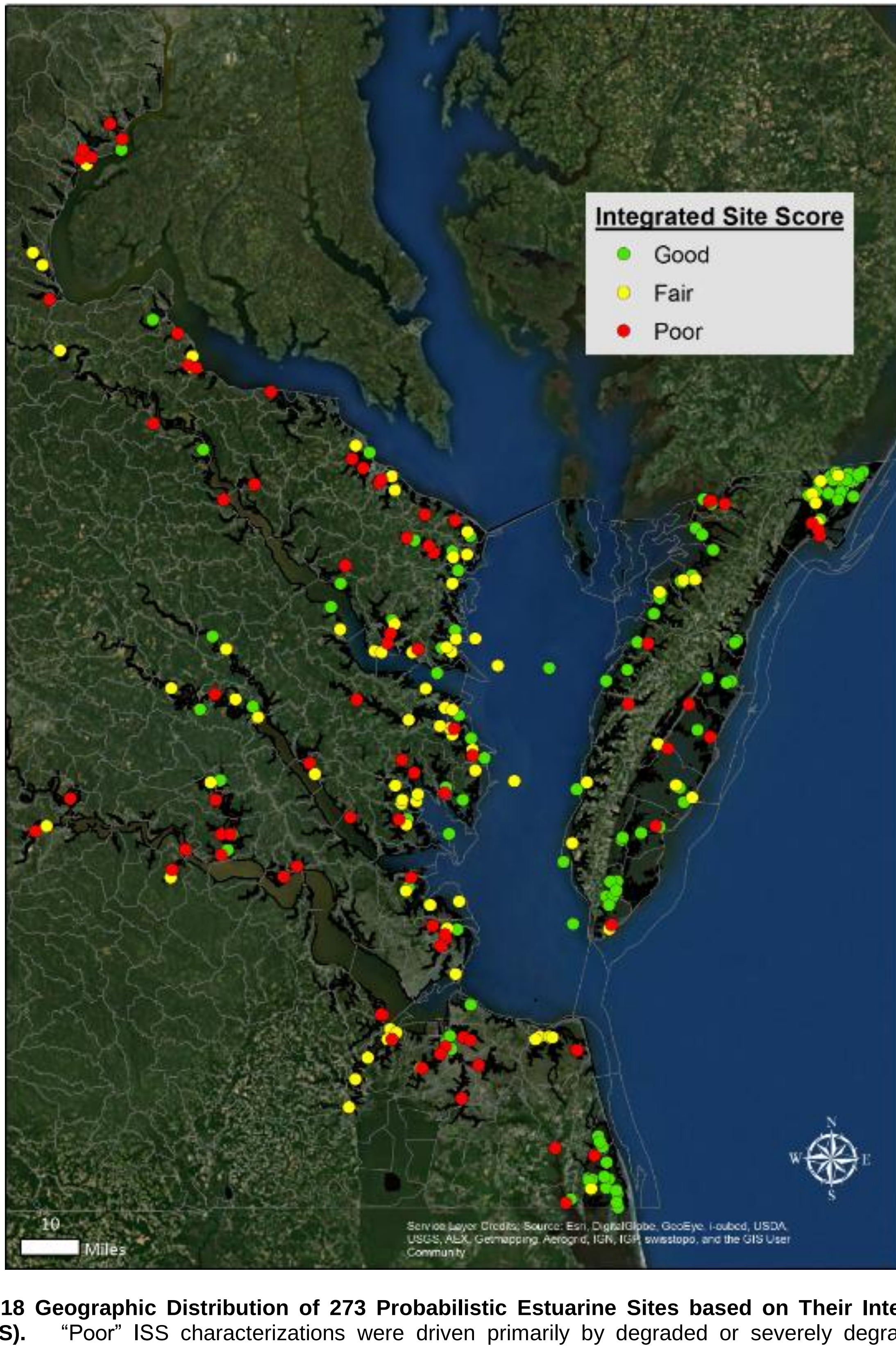


Figure 4.5-18 Geographic Distribution of 273 Probabilistic Estuarine Sites based on Their Integrated Site Scores (ISS). "Poor" ISS characterizations were driven primarily by degraded or severely degraded benthic communities, by high chemical contamination independently of benthic degradation, and by poor water clarity which depressed the WQI characterizations.

If elevated chemical contamination and/or sediment toxicity is observed in conjunction with a degraded or severely degraded benthic community, an assessment of "5A – Impaired" (by toxics) is assigned. If a degraded or severely degraded benthic community is observed without chemical or toxicological corroboration, an assessment of "3B - observed effects with insufficient information" is assigned, although ancillary information may suggest a possible cause other than toxics. A "3B" assessment is also assigned if sediment contamination exceeds sediment quality guidelines specified in the Guidance Manual, but benthic scores are still acceptable. Statistically and ecologically significant sediment toxicity, without chemical corroboration or benthic degradation, is assigned assessment category "2B - waters are of concern to the state but no Water Quality Standard exists for a specific pollutant, or the water exceeds a state screening value. If no benthic degradation, sediment chemical contamination, or sediment toxicity are observed, an assessment category "2A" is assigned "- waters are attaining all of the uses for which they are monitored (based on the data in the WOE workbook) and there is insufficient data to document the attainment of all [other] uses." Assessments of "2A" or "2B" are characterized as "Good", assessments of "3B" are characterized as "Fair", and assessments of "5A" are characterized as "Poor." Because the assessment category of "5A – Impaired" for ALU is only assigned in cases where benthic degradation is corroborated by sediment chemical contamination and/or sediment toxicity, the proportion of sites in this category is less than that observed for many other individual parameters or indices.

From a total of 273 sites, 114 (41.8 ± 5.9%) were assessed as "Good" (2A or 2B), 146 (53.5 ± 5.9%) were assessed as "Fair" (3B), and only 13 (4.8 ± 2.5%) were assessed as "Poor" (5A – Impaired for ALU). It must be kept in mind that the low number of 5A – Impaired sites (4.8 ± 2.5%) in comparison with the number of degraded or severely degraded benthic community sites (44.7 ± 5.9%) results from the fact that the WOE assessment is specifically directed at toxics. If benthic degradation by toxics was not substantiated within the sediment quality triad, the WOE assessment was a Category 3 – "Observed effects", with insufficient data to assign a cause and the site was prioritized for follow-up monitoring. Although NCCA Reports provide no thresholds for evaluating weight-of-evidence assessments with the sediment quality triad, the fact that the results contained fewer than 15% but questionably fewer than 5% "Poor" characterizations (based on Sediment Quality Index regional thresholds - Table 4.5-18), Virginia's estuaries should probably be characterized as "Fair" on the whole.

The geographic distribution of these results is illustrated in the map of Figure 4.5-19. Once again, the variable of interest is expressed in a discontinuous, non-quantitative ordinal scale, and statistical and cumulative probability distributions are not presented or appropriate.

Relative Prevalence of Stressors and Indicators*:* In the previous sections we have characterized Virginia's estuarine waters evaluating a number of individual potential stressors and several integrated stressor indices, as well as several measures of observed effects. It seems appropriate at this point to summarize and evaluate the prevalence of these stressors and indices relative to one another and to the Commonwealth's estuarine waters as a whole.

One individual element (*i.e.*, **water clarity**) of the conventional five-element Water Quality Index (WQI_5) characterized over 53% of Virginia's estuarine waters as being in "Poor" condition (Table 4.5-21 and Figure 4.5-20 below), also with a statewide evaluation of "Poor." The controversy about the appropriateness of water clarity and the difficulty with its interpretation were discussed in considerable detail earlier. It was the single most prevalent stressor evaluated in this report, and its inclusion increased "Poor" characterizations by the integrated WQI from 1.5% (WQI_4) to 17.5% (WQI_5) and "Poor" characterization by the Integrated Site Score from 23.1% (ISS_4) to 28.6% (ISS_5).

The second most prevalent indicator is the degradation of benthic communities, as indicated by the **Benthic Index of Biotic Integrity (B-IBI)**. The B-IBI is actually an index of observed effects rather than a direct measure of stressors. It integrates the effects of all stressors impacting the benthic community, and indicates that the benthic communities in approximately 44.7% of Virginia's estuarine waters are degraded to some extent, resulting in a statewide characterization of "Poor" for benthic quality. Such degradation may be a consequence of nutrient enrichment (eutrophication), often causing a consequent depression of bottom dissolved oxygen concentrations, or of excessive sedimentation smothering the benthos, or may result from the chronic or acute effects of chemical contamination. Natural processes such as scouring by strong tidal currents, dynamic wave action, and heavy predation pressure may also locally degrade benthic communities. Consequently, it is often difficult to identify the specific stressor or combination of stressors responsible for benthic degradation. The weight of evidence assessment discussed elsewhere in this report attempts to integrate various lines of toxics-related evidence to explain the variations in B-IBI scores, but observed site-specific chemical contamination, the acute toxicity observed in short-term laboratory tests, and the associated site B-IBI results don't always agree. Longer duration, chronic toxicity tests might resolve some of

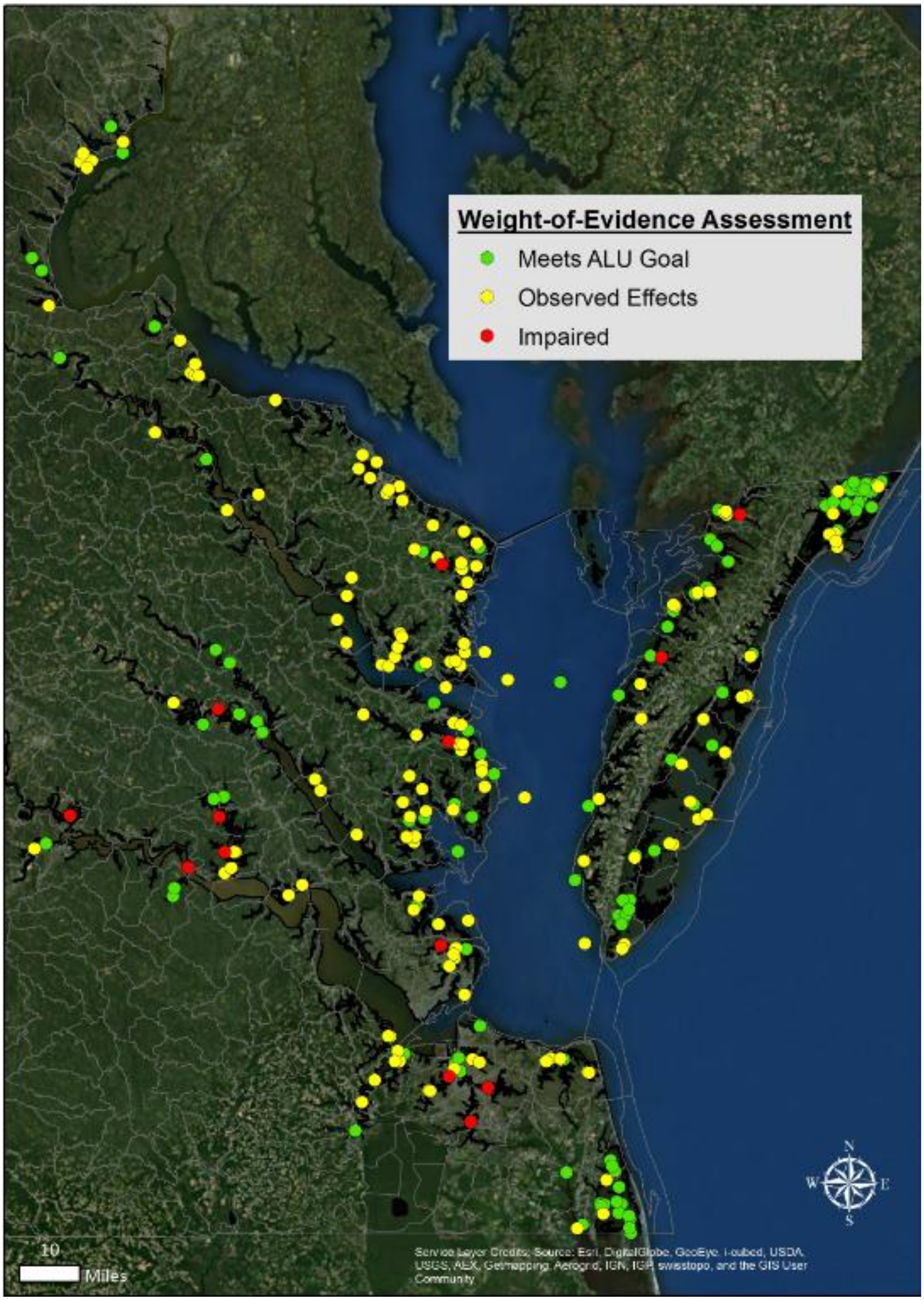


Figure 4.5-19 The geographical distribution of 273 Probabilistic Estuarine Sites based upon Weight-of-Evidence (WOE) Aquatic Life Use (ALU) Assessments using the Sediment Quality Triad (SQT). This ALU assessment was carried out solely on the basis of toxics. Sites with degraded or severely degraded benthic communities were assigned to assessment category “3B - observed effects with insufficient information” if no corroborating evidence of contamination or toxics effects was observed.

Table 4.5-21 Summary of Site Attributes and the Prevalence of "Poor" Characterizations among 273 Probabilistic Estuarine Sites sampled from 2007 to 2012. The most prevalent stressor was water clarity, which was characterized as "Poor" at 53.5 % of the sites following integrated NCCA and CBP criteria. Refer to Figure 4.5-20, below, and to the text for more detail. The stoplight colors in the "Abbreviation" column indicate the statewide characterization (Good, Fair or Poor) resulting from each measure. Note the influence of including or excluding water clarity in the percentage poor characterizations by the Water Quality Index (WQI) and the Integrated Site Score (ISS), highlighted in light yellow and green in the last three columns.

Site Attributes	Designated Use	Abbreviation	% of Area in "Poor" Class	Lower Limit 95% CI	Upper Limit 95% CI
Integrated Site Score (ISS_5) - 3 Elements (WQI_5, SQI, B-IBI) with Clarity [1]	ALU	ISS_5	28.57%	23.19%	33.95%
Integrated Site Score (ISS_4) - 3 Elements (WQI_4, SQI, B-IBI) without Clarity [1]	ALU	ISS_4	23.08%	18.06%	28.10%
1 Water Quality Index (WQI_5) - 5 Elements [1]	ALU	WQI_5	17.45%	12.94%	21.96%
Water Quality Index (WQI_4) - 4 Elements (without Clarity) [1]	ALU	WQI_4	1.45%	0.03%	2.87%
1 Chlorophyll (Chl-a) - > 20 µg/L	ALU	Chl-a	14.39%	10.19%	18.59%
2 Dissolved Inorganic Nitrogen (DIN) - > 0.5 mg/L	ALU	DIN	1.09%	0.00%	2.32%
3 Dissolved Inorganic Phosphorus (DIP) - > 0.05 mg/L	ALU	DIP	6.91%	3.90%	9.92%
4 Dissolved Oxygen - bottom (DO_{Bot}) - CBP criterion < 3.2 mg/L	ALU	DO_{-Bot}	4.74%	2.21%	7.27%
5 Water Clarity (Clarity) - mixed criteria	ALU	Clarity	53.48%	47.54%	59.42%
Bacteria - Human Health (*Enterrococcus* spp., *Escherichia coli* - Bact)	PRC	Bact	6.23%	3.35%	9.11%
Dissolved Metals (mean Chronic Standard Quotient)	ALU	$mCSq_{-met}$	1.65%	0.00%	3.51%
2 Sediment Quality Index (SQI) - 3 Elements [1]	ALU	SQI	13.87%	9.76%	17.98%
1 Sediment Toxicity - (SedTox) - Control-corrected survivorship < 80% and statistically significant	ALU	SedTox	4.74%	2.21%	7.27%
2 Sediment Chemistry (SedChem) - NCCA ERM & ERL exceedance counts	ALU	ERL-ERM	2.55%	0.67%	4.43%
Sediment Chemistry (SedChem) - mean ERM Quotient > 0.098	ALU	mERMq	8.00%	4.80%	11.20%
Sediment Chemistry (SedChem) - Equilibrium Partitioning Sediment Benchmark - PAH Mixtures (ESB_{34})	ALU	ESB_{-34}	20.80%	16.00%	25.60%
3 Sediment Total Organic Carbon (TOC) - > 5%	ALU	TOC	3.65%	1.42%	5.88%
3 Benthic Community Index (B-IBI) [2] - Varying numbers of metrics	ALU	B-IBI [1]	44.73%	38.83%	50.63%
Weight-of-Evidence (WOE) Assessment[2,3] - Observed Effects	ALU	WOE [1,3]	4.00%	1.67%	6.33%

[1] Integrated Stressor Indices
[2] These indices are of observed effects, not stressors.
[3] WOE Toxics assessment based on the Sediment Quality Triad.

ALU - Aquatic Life Use
PRC - Primary Contact Recreation (Human Health)

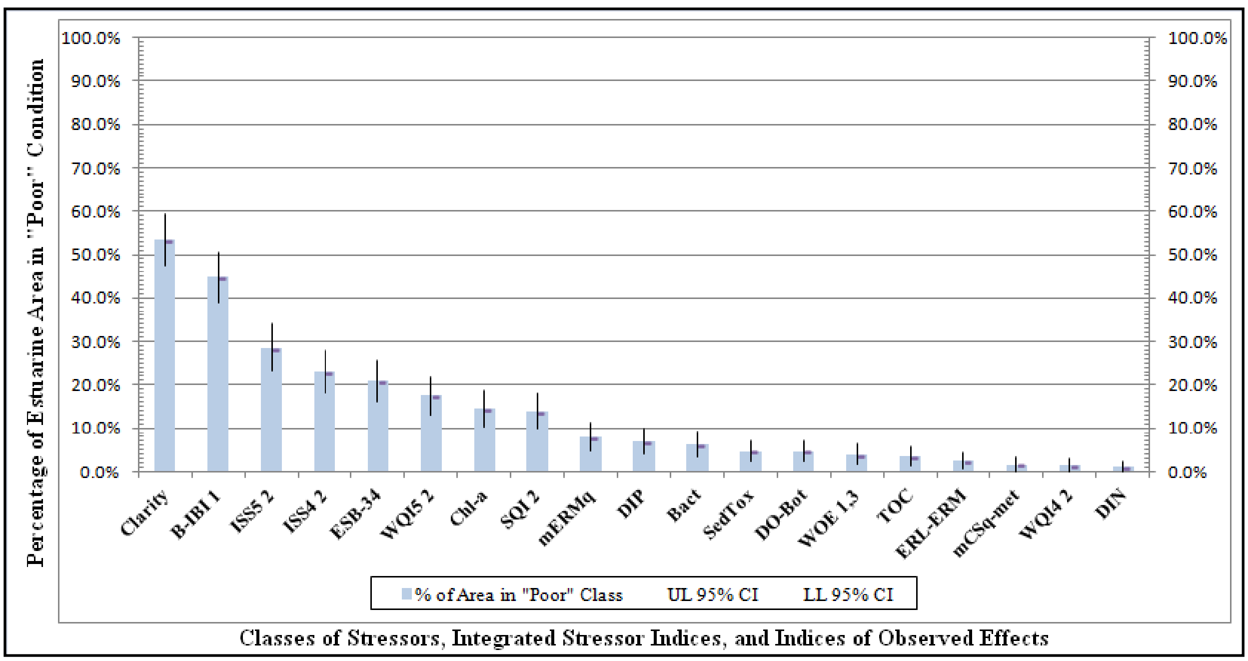


Figure 4.5-20 Relative Prevalence of Observed Stressors and Measures of Observed Effects. The percent of sites in the "Poor" class with its 95% confidence interval (UL = Upper Limit and LL = Lower Limit). See Table 4.5-21 above for exact percentages. Theoretically, with equal weight probabilistic sampling, the proportion of sites with a specified characteristic is equivalent to the proportion of the total estuarine area with the same characteristic. [1] Indices of "Observed Effects"; [2] Integrated Site Indices; [3] The WOE Assessment is predicated solely on a toxics evaluation employing the "Sediment Quality Triad."

the differences, but the increased time required for such tests and the added cost considerations would be prohibitive.

Integrated Site Scores, both with (ISS_5) and without (ISS_4) the inclusion of water clarity, are next in prevalence. This is not surprising, because they each incorporate two integrative measures of stressors (WQI, SQI), plus they both include the B-IBI effects measure - the second most prevalent indicator - as one of the three elements in their calculation. When water clarity is included in the Water Quality Index (WQI_5), the ISS_5 characterizes 28.6% of Virginia's estuarine waters as "Poor." The proportion of estuarine waters characterized as "Poor" drops to 23.1% when water clarity is excluded and the ISS_4 is calculated using the WQI_4. The numerical average of the individual ISS scores would give Virginia a statewide "Fair" characterization under either of these scenarios.

The fifth most prevalent stressor measure is the **Equilibrium Partitioning Sediment Benchmark for PAH mixtures (ESB_{34})**, which characterized the sediment as "Poor" in 20.8% of estuarine waters. Applying the sediment contaminant thresholds in NCCA Report IV, this would give Virginia a regional characterization of "Poor" for sediment contamination. The prevalence of (primarily) pyrogenic PAHs in the sediment of the Chesapeake western shore (Figure 4.5-14) closely parallels the demographic development and the activities of small private vessels and commercial/military shipping, as well as being in agreement with the highest density of degraded and severely degraded benthic communities (Figure 4.5-17). These PAHs are pervasive, adsorbed and transported by fine sediment particles, but are at extremely low concentrations in the interstitial waters. Their influence is not evident in short-term acute toxicity tests, but chronic effects on the survival of juvenile benthos, and on their subsequent growth and reproduction may be significant.

The **five-element Water Quality Index (WQI_5)**, with water clarity, is the sixth most prevalent indicator, characterizing approximately 17.5% of Virginia's estuarine waters as being in "Poor" condition, which would give Virginia a regional characterization of "Fair." As an indication of the strong influence of the water clarity metric on the WQI, the four-element index **(WQI_4 - without the inclusion of water clarity)** is seventeenth in prevalence, and only characterizes 1.5% of the Commonwealth's estuarine waters as "Poor." As a further confirmation of the difficulty in measuring and evaluating water clarity as a measure of water quality, the Chesapeake Bay Program evaluates both water clarity and the prevalence of Submerged Aquatic Vegetation (SAV - that depends upon the clarity), separately and by considering the best single year in a block of three consecutive years. Clearly, water clarity (pardon the redundancy pun) is complex!

Excessive near-surface **chlorophyll concentration (CHLa**) is ranked as the seventh most prevalent stressor and indicates that 14.4% percent of the estuarine waters are in "Poor" condition. This would give Virginia's estuaries a regional characterization of "Fair." Excessive chlorophyll, in the form of planktonic algal blooms, contributes to poor water clarity, as do total suspended solids (TSS) that are not considered as an independent element in the NCCA water quality index. Chlorophyll and TSS concentrations are both significantly and negatively correlated with water clarity measurements, accounting respectively for 12.5% and 12.3% of the total observed variations in water clarity (measured as % light availability at a depth of 1.0 meter).

The eighth most prevalent indicator is the **Sediment Quality Index (SQI -** an integration of sediment toxicity, sediment contamination, and sediment total organic carbon) that characterizes 13.9% of Virginia's estuarine area as having "Poor" sediment quality, and results in a statewide regional classification of "Fair." For this report, toxicity was represented with the DEQ-adapted scale as shown in Figures 4.5-10 and 4.5-11-B. The SQI was calculated with a sediment contamination element expressed as the mean ERM Quotient (mERMq). The mERMq is intermediate in sensitivity between the NCCA count of ERL and ERM exceedances (ERL-ERM - very low sensitivity - see discussion below) and the Equilibrium Partitioning Sediment Benchmark for PAH mixtures (ESB_{-34} - very high sensitivity - see discussion above). The sediment TOC element was expressed following the NCCA guidelines summarized in Figure 4.5-15.

The mean **ERM Quotient (mERMq)** was the ninth most prevalent metric, classifying sediments in 8.0% of Virginia's estuarine waters as being in "Poor" condition. This would result in a statewide regional characterization of "Fair" for estuarine sediment contaminants.

Dissolved inorganic phosphorus (DIP) was at "Poor" concentrations in 6.9% of the state's estuarine waters, making it the tenth most prevalent stressor. The resultant regional characterization would be an overall "Good" classification for DIP, since fewer than 10% of sites scored "Poor" and slightly more than 50% of the sites scored "Good."

Bacterial contamination was the eleventh most prevalent stressor, with bacteria of the genus *Enterococcus* or *E. coli* exceeding Virginia's saltwater or freshwater standards, respectively, for human primary contact recreation at 6.2% of the estuarine sites. Although no threshold values were provided in previous NCCA reports, best professional judgment would suggest that because almost 72% of the samples contained no detectable bacteria of interest ("Good"), and bacterial water quality standards were exceeded ("Poor") in less than 10% of the samples, the overall condition of Virginia's estuarine waters based on bacterial contamination was "Fair" to "Good"!

Sediment toxicity (SedTox) ranked as the twelfth most prevalent stressor, classifying 4.7% of estuarine sites as "Poor" for acute toxicity using DEQ's adapted toxicity thresholds. Keep in mind that a number of the "Poor" characterizations resulted from iron-fixing bacterial activity (pH depression), and not from chemical contamination. The traditional NCCA threshold for regional characterization of sediment toxicity is 5 percent, five percent or more of the sites would give a regional characterization of "Poor" while less than five percent would give a characterization of "Good" (no "Fair" characterization possible). Because the 95% confidence intervals on the percentages of "Poor" versus "Good" sites includes five percent under both the traditional NCCA scoring and the DEQ adapted scoring, it would seem reasonable to give a regional characterization of "Fair" under either system.

Near bottom dissolved Oxygen concentrations (DO_{-bot}) were tied with sediment toxicity in relative prevalence, reaching "Poor" concentrations (< 3.2 mg/L – CBP DO criterion) at 4.7% of the sites evaluated. Under the NCCA criterion for "Poor" (< 2.0 mg/L) only 0.4% of the sites would earn this characterization. Either criterion would give Virginia's estuarine waters an overall "Good" rating.

Weight-of-Evidence (WOE) assessment of the Aquatic Live designated Use (ALU) for toxics was the fourteenth ranked indicator, with only 4.0% of estuarine sites characterized as "Poor." It is an index of "observed effects" rather than a direct measure of stressor intensity, and is relatively insensitive in that an "impaired" (5A = "Poor") assessment was only given when all three lines of evidence (high chemical contamination, significant sediment toxicity, and poor benthic community health) of the sediment quality triad were in agreement. Compared with the NCCA thresholds for the sediment quality index (SQI), Virginia's estuaries would earn a regional characterization of "Fair" for toxics-related ALU assessments based on the sediment quality triad.

Sediment Total Organic Carbon (TOC) was rated as "Poor" at only 3.7% of the sites, making it the fifteenth in prevalence. Virginia estuaries would receive an overall "Good" rating based on the prevalence of sediment TOC.

The **NCCA sediment contamination measure (ERL-ERM)**, based on the numbers of exceedances of ERM and ERL sediment screening values, only characterized 2.6% of the sites as being in "Poor" condition. This was the sixteenth in prevalence and would give Virginia an overall "Good" rating for sediment contamination. As pointed out earlier, this is a rather insensitive measure, since it does not take into account the additive or synergistic effects of multiple contaminants that are below their respective ERM or ERL concentrations.

The integrated dissolved metals measure, the **mean Chronic Standard Quotient ($mCSq_{-met}$)**, only classified 1.7% of Virginia's estuarine waters as "Poor," making it the seventeenth in prevalence. Two of the three sites characterized as poor did not exceed any standard for dissolved metals, but were so classified because their dissolved Copper concentrations were above one half of the chronic saltwater standard (Table 4.5-8 and Figure 4.5-9). Overall, Virginia's statewide estuarine characterization would be "Good" for dissolved metals.

The **four-element Water Quality Index (WQI_4)**, without the water clarity metric, only characterized 1.5% of Virginia's estuarine waters as being "Poor" for water quality, and earned a "Good" as a regional rating. Of the four individual elements included in this index (Chl-a, DIN, DIP, and DO_{-bot}), only chlorophyll rated an overall characterization of "Fair." All other elements earned "Good" for their regional characterizations.

Dissolved Inorganic Nitrogen (DIN) only reached "Poor" concentrations at 1.1% of Virginia's estuarine sites (Figure 4.5-3), and earned a regional characterization of "Good." Elevated ("Fair" & "Poor") DIN concentrations were localized primarily in the Occoquan region of the upper tidal Potomac River, the western and southern branches of the Elizabeth River system, and in the lower Pamunkey River.

Merging all nineteen of these individual stressor evaluations, integrated stressor indices, and measures of observed effects into a final characterization of Virginia's estuarine waters is a challenge. Two of the evaluated stressors, water clarity (in spite of the difficulty in its interpretation) and sediment contamination, appear to be the most prevalent detriments to aquatic life use. These two stressors are integrated into, respectively, the Water Quality Index (WQI_5) and the Sediment Quality Index (SQI). Both of these Integrated Indices characterized Virginia's estuarine waters as a whole as being in fair condition. These two indices were integrated with the Index of Benthic Condition (B-IBI score), site by site, to calculate an Integrated Site Score (ISS), using the scoring procedure adapted from NCCA Report IV (U.S. EPA, 2012). Figure 4.5-18 shows a map representation of these results, which are also summarized in Figure 4.5-21 – 42.1% "Good", 29.3% "Fair", and 28.6% "Poor".

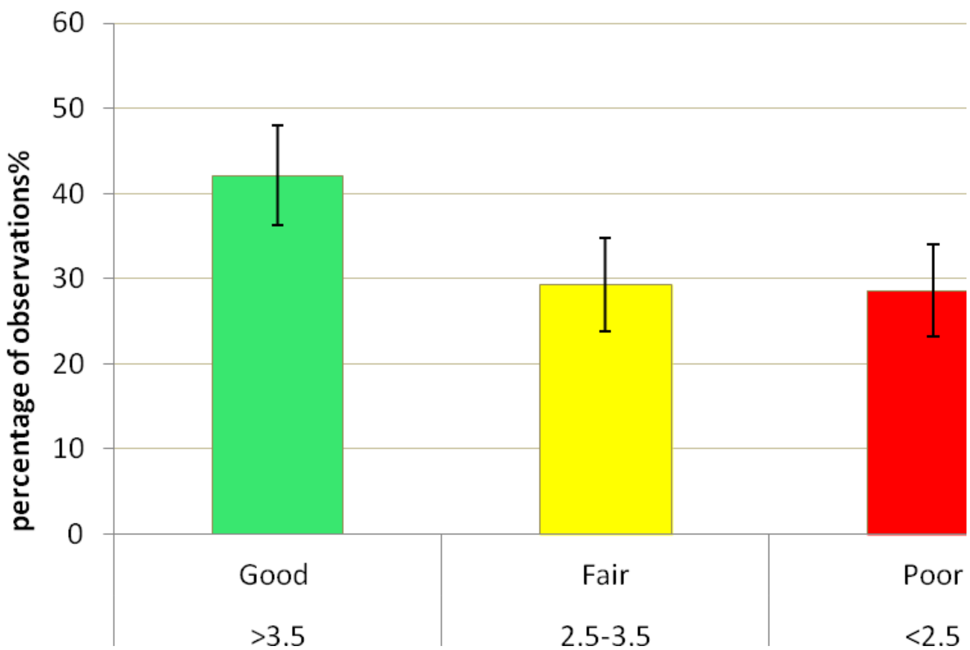


Figure 4.5-21. Summary of Integrated Site Score (ISS) Characterizations of 273 Probabilistic Estuarine Sites based on their WQI_5, SQI, and B-IBI Scores. The WQI_5 includes the Water Clarity criterion (see 9VAC25-260-185) and Figure 4.5-7-A). The overall average of ISS values was 3.10, which would give Virginia's estuarine waters an overall, regional score of "Fair."

The arithmetic average ISS across all 273 sites in this report was 3.1, giving an overall characterization of Virginia's estuarine waters as "Fair." This average (3.1) is almost exactly in the center of the range between "Good" and "Poor." Clearly it could have been worse, but it could also be much much better. We still have a long way to go in attaining our ultimate goals of clean water, uncontaminated sediment, and healthy aquatic life communities. The upcoming National Coastal Condition Report V, to be published before the end of the year, may provide sufficient information to compare Virginia's estuaries with those of other states in the northeastern region. Wherever we stand relative to other states, however, our commitment to improving Virginia's waters must stand alone and remain firm.

Current discussions related to the next planned National Coastal Condition Assessment, in the summer of 2015, are considering the inclusion of new measures addressing additional environmental stressors, such as ocean acidification and climate change. Hopefully, the inclusion of new measures, as well as advancements in the methods and representativeness of established measures, will improve our ability to detect, identify the source(s) of, and remediate problems in the Commonwealth's estuarine waters, to improve the health of our estuaries for future generations – human, animal, and vegetal.

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